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1949

COMMITTEE REPORTS

TECHNICAL PAPERS

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FOREWORD

The *Proceedings* of the American Society for Testing Materials are published annually and include all reports and papers offered to the Society during the current year and accepted by the Administrative Committee on Papers and Publications for the *Proceedings*, together with discussion.

The table of contents and subject and author indexes cover all papers and reports published by the Society during the current year, which in addition to those appearing in the *Proceedings* includes those accepted for publication in the ASTM BULLETIN or as Special Technical Publications.

A list of the Special Technical Publications published by the Society in 1949 is given on the last page of this volume. This supplements the list appearing in the 1948 *Proceedings* covering all special publications published by the Society up to 1948.

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A Direct Reading Portable Photoelectric Photometer for Determining Reflectance of Highway Centerlines—John M. Hill and Howard W. Ecker (see ASTM BULLETIN *No. 159, July, 1949, p. 69 (TP 129)).*

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SUMMARY OF PROCEEDINGS
OF THE
FIFTY-SECOND ANNUAL MEETING

ATLANTIC CITY, N. J., JUNE 27–JULY 1, 1949

The following Summary records the action taken by the Society at the Annual Meeting on the Recommendations Affecting Standards appearing in the annual reports of the technical committees. In the individual committee reports attention is called through an editorial footnote to any modifications of the recommedations or where the recommendations of the committee were not approved. In all other instances it is to be understood that the recommendations were approved as submitted by the committee. The new and revised standards and tentatives are published in the 1949 Book of A.S.T.M. Standards. Except as noted, the reports and papers appear in this volume.

This summary of the Fifty-second Annual Meeting of the American Society for Testing Materials, held at the Chalfonte-Haddon Hall Hotel, Atlantic City, N. J., June 27–July 1, 1949, is a record of the transactions of the meeting, including the actions taken on the various recommendations submitted by the technical committees. In all, 22 technical sessions and 3 informal sessions were held.

The registered attendance of the meeting is as follows: Members present or represented, 1092; committee members, 530; guests, 235; total 1857; ladies, 345.

The Proceedings are set forth session by session. There were 57 reports and 105 formal papers presented. The record with respect to each has been briefed, the recommendations in the reports having been grouped so as to cover the acceptance of material for publication as tentative, such as new specifications, methods of test, revisions of tentatives, and proposed revisions of existing standards, and as a separate group, the approval of matters that were referred to letter ballot of the Society, comprising the adoption of tentatives as standard and the adoption of revisions of standards. Accordingly, wherever the action is reported as "adopted as standard" or "adopted as standard, revisions in" it is understood that this indicates approval of the Annual Meeting for reference to letter ballot of the Society. The various recommendations so recorded are included in the Society letter ballot.[1] The actions designated as "accepted as tentative" or "accepted as tentative, revisions in," are self-evident as indicating acceptance by the Society at the Annual Meeting for publication as tentative.

While all of the items on the program are recorded under the particular session in which they were presented, for convenience in locating actions with respect to any particular report, the accompanying list is presented of all the reports together with the page reference where the action thereon is recorded:

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[1] The letter ballot on recommendations affecting standards, distributed to the Society membership, was canvassed on September 30, 1949, and all actions were approved.

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Recent Progress in High Speed Flash Radiography—J. C. Clark, presented from manuscript by the author.

10 Mev. X-Ray Technique—D. T. O'Connor, E. L. Cruiscuolo, and Artie Pace, presented from manuscript by Mr. O'Connor.

Mobilizing the Van de Graaff Generator for Precision Radiography—E. A. Burrill, presented from manuscript by the author.

A Universal Exposure Calculator for Radium Radiography and Its Application to Current Industrial Radiographic Films and Techniques—N. A. Kahn, E. A. Imbembo, and Jay Bland, presented from manuscript by Mr. Kahn.

A Discussion on Radiographic Sensitivity—Carlton H. Hastings, presented from manuscript by the author.

A Revised Procedure for Establishing Radiographic Standards—L. W. Ball, presented from manuscript by the author.

FIRST SESSION—OPENING SESSION; FATIGUE OF METALS

MONDAY, JUNE 27, 8 P.M.

SESSION CO-CHAIRMEN: PRESIDENT R. L. TEMPLIN AND PAST-PRESIDENT J. R. TOWNSEND

President Templin, in opening the Fifty-second Annual Meeting extended a cordial welcome to all members and guests of the Society in attendance. He noted briefly that there were 105 technical papers and 57 committee reports to be presented, making a total of 162 items distributed among the 25 sessions. He pointed out that about half of this information has been preprinted for the meeting making a total of around 1500 pages which is as much preprinted material as ever before published by the Society for an Annual Meeting. He referred to the 450 meetings scheduled for the week, which exceeded any previous Annual Meeting. In conclusion, Mr. Templin stated that from the expected attendance, the number of committee meetings, and the number of interesting technical sessions this promised to be one of the largest and most successful meetings held by the Society.

Minutes of Fifty-first Annual Meeting

The minutes of the Fifty-first Annual Meeting were distributed during the summer of 1948 as a Summary of Proceedings. This summary is published in the 1948 *Proceedings*.[3] On motion, the minutes were approved.

Report of Board of Directors

In presenting the Report of the Board of Directors, the Executive Secretary, C. L. Warwick, called attention first to the reports of the following Administrative Committees that were appended to the report:

- Administrative Committee on Standards
- Administrative Committee on Research
- Administrative Committee on Papers and Publications
- Administrative Committee on Ultimate Consumer Goods
- Administrative Committee on Simulated Service Testing
- Administrative Committee on District Activities

These brief reports summarized the activities in the designated fields of work.

Mr. Warwick pointed out that this past year has seen the work of the Society expand into important new fields, which in turn has brought into the Society new members to work out their testing and specification problems in the environment and under the established procedures of A.S.T.M. He also emphasized the significance of the first national meeting west of the Rockies, to be held in October in San Francisco, which is far reaching since it is the first time that the work of A.S.T.M. will be carried so intimately to its members in the rapidly growing industries in the Pacific Area. Mr. Warwick further stressed the great activity by the members and Society committees in both standardization and research on engineering materials. He reviewed a number of important aspects of the Society's work, including membership; meetings, both national and local; headquarters; publications; technical activities; organization of new committees; relations with other organizations; cooperation with the American Standards Association; and consideration of international standardization activities.

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[2] To be issued as a separate publication.

[3] Summary of Proceedings of the Fifty-first Annual Meeting, *Proceedings*, Am. Soc. Testing Mats., Vol. 48, p. 1 (1948).

An amendment of the By-laws was presented for action as given in detail in the Report of the Board of Directors. This amendment proposes that the following sentence in Article I, Section 7, of the By-laws dealing with honorary members be changed from its present form, namely, "The number of Honorary Members shall not exceed twenty," to read: "The number of Honorary Members shall be left to the discretion of the Board of Directors." Consideration of matters relating to the election of honorary members had led the Board to feel that it will be in the better interests of the Society if the number of honorary members be not limited in the By-laws but left to the discretion of the Board.

On motion, duly seconded, it was

VOTED that the proposed amendment be referred to letter ballot of the Society.

On motion duly seconded, the report of the Board of Directors was accepted for publication in the *Proceedings.*

The chair was then turned over to Mr. J. R. Townsend, who presided during the presentation of papers on the Fatigue of Metals as recorded below.

Papers:

The Influence of Fluctuations in Stress Amplitude on the Fatigue of Metals—T. J. Dolan, F. E. Richart, Jr., and C. E. Work, presented by Mr. Dolan.

The Effects of Spray Metallizing Procedures on the Fatigue of Steel—W. Lee Williams, presented by the author.

A New High-Speed Sheet Metal Fatigue Testing Machine for Unsymmetrical Bending Studies—G. R. Gohn and E. R. Morton, presented by Mr. Gohn.

Dynamic Creep and Rupture Properties of Temperature-Resistant Materials Under Tensile Fatigue Loading—B. J. Lazan, presented from manuscript by the author.

Effect of Pulsating Loads on the Creep Characteristics of Aluminum Alloy 14S-T.—M. J Manjoine, presented by the author.

SECOND SESSION—SOILS

TUESDAY, JUNE 28, 9 A.M.

SESSION CHAIRMAN: K. B. WOODS

Committee D-18 on Soils for Engineering Purposes:

Report presented from manuscript by E. J. Kilcawley, chairman, and accepted as a report of progress.

Papers:

The Procedure and Significance of Chemical and Mineralogical Tests on Soils—T. William Lambe and V. F. B. de Mello, presented by Mr. Lambe.

Subsurface Explorations by Geophysical Methods—E. Raymond Shepard, presented by the author.

Study on Mechanical Oscillators—R. K. Bernhard, presented by the author.

THIRD SESSION—SYMPOSIUM ON RAPID METHODS FOR THE IDENTIFICATION OF METALS[2]

TUESDAY, JUNE 28, 10 A.M.

SESSION CHAIRMAN: L. A. WOOTEN

Introductory Remarks—L. A. Wooten.

Development, Present State, and Outlook of Spot Test Analysis—Fritz Feigl, presented from manuscript by the author.

Electro Spot Testing and Electrography—H. W. Hermance and H. V. Wadlow, presented from manuscript by Mr. Wadlow.

Instruments for Rapid Metal Identification—R. R. Webster, presented from manuscript by the author.

[*Symposium continued in Fifth Session*]

FOURTH SESSION—LUNCHEON, PRESIDENT'S ADDRESS, RECOGNITION OF 40- AND 50-YEAR MEMBERS, AND INTRODUCTION OF NEW OFFICERS

TUESDAY, JUNE 28, 12:15 P.M.

CHAIRMAN: PAST-PRESIDENT T. A. BOYD

One of the innovations at the Annual Meeting was the scheduling of a luncheon as an official session at which about 300 members and guests were present. During the luncheon, the annual address of the President was presented, the first awards of 50-year certificates were made, and also the 40-year members were recognized. Past-President J. R. Townsend presented the Past-President Pin to retiring President R. L. Templin. Mr. Templin, in recognizing Mr. Townsend, commented on the latter's outstanding record of service as an officer of the Society which occasioned a special letter of appreciation from the Board of Directors on his retirement from the Board.

Election of Officers:

Results of the letter ballot on election of new officers were announced by the Chairman of the Tellers' Committee, E. J. Albert. Of the 1036 ballots cast, the results were as follows:

For President, to serve for one year:
  J. G. Morrow, 1036 votes
For Vice-President, to serve for two years:
  R. E. Richart, 1036 votes.
For Directors, to serve for three years:
  R. D. Bonney, 1036 votes.
  C. H. Fellows, 1036 votes.
  H. F. Gonnerman, 1036 votes.
  N. L. Mochel, 1036 votes.
  M. O. Withey, 1036 votes.

The newly elected members of the Board of Directors who were present were introduced, as was the new President, J. G. Morrow, who spoke briefly. The new Vice-President, Prof. F. E. Richart, was absent because of illness.

Executive Secretary Warwick gave brief citations for the 50-year members after which specially engrossed framed certificates were tendered by Mr. Templin. The 40-year members were also noted by Mr. Warwick and each received the 40-year certificate.

Presidential Address:

The chairman presented the President, R. L. Templin, who delivered the presidential address entitled, "The Progress of A.S.T.M."

FIFTH SESSION—SYMPOSIUM ON RAPID METHODS FOR THE IDENTIFICATION OF METALS *(continued from Third Session)*

TUESDAY, JUNE 28, 2:30 P.M.

SESSION CHAIRMAN: S. E. Q. ASHLEY

Committee E-3 on Chemical Analysis of Metals:

Report presented by D. R. Evans, chairman, and the following actions taken:

Adopted as Standard:

Chemical Analysis of Special Brasses and Bronzes (E 54 - 46 T)
Chemical Analysis of White Metal Bearing Alloys (E 57 - 46 T)
Chemical Analysis of Lead- and Tin-Base Solder Metal (E 46 - 46 T), as revised

Adopted as Standard, Revisions in:

Chemical Analysis of Aluminum and Aluminum-Base Alloys (E 34 - 45)
Chemical Analysis of Magnesium and Magnesium-Base Alloys (E 35 - 45)

Papers:

This session was a continuation of the Symposium on Rapid Methods for the Identification of Metals.[2] The papers presented at this session are listed below:

Separating Alloys by Relative Spot Tests—H. Kirtchik, presented from manuscript by the author.
Rapid Methods for the Identification of Copper-Base Alloys—R. P. Nevers, presented from manuscript by the author.
Rapid Identification of Metal Finishes—D. R. Evans and A. Lewis, presented from manuscript by Mr. Lewis.
Examination of Plated and Protective Coatings by Electrographic Analysis—N. Galitzine and S. E. Q. Ashley, presented from manuscript by Mr. Galitzine.
Separating Tin-Lead, Antimony-Lead, and Pure Lead by Spot Test Analysis—C. A. Ray, presented from manuscript by the author.
A Field Test Kit for Rapid Identification of Nickel Alloys—H. B. Lea, presented from manuscript by the author.
Rapid Tests for Identifying Alloy Steels—Elbert C. Kirkham, presented from manuscript by the author.

PAPERS ON ULTRASONIC TESTING[2]

TUESDAY, JUNE 28, 2:30 P.M.

SESSION CHAIRMAN: H. C. AMTSBERG

Basic Principles of Ultrasonic Testing—J. C. Smack, presented from manuscript by the author.
Ultrasonics in the Heavy Forging Industry—J. C. Hartley, presented from manuscript by the author.
Application of Ultrasonics to the Fabrication of Aluminum—J. V. Carroll, presented from manuscript by the author.
Ultrasonics in the Railroad Industry—E. D. Hall, presented from manuscript by Mr. S. E. Ladner.
Ultrasonics in the Electrical Industry—D. M. Kelman, presented from manuscript by the author.
Application of Ultrasonics to Naval Problems—H. M. Trent, presented from manuscript by the author.
Application of Ultrasonics to Bronze Forgings and Ingots—A. Piltch, presented from manuscript by the author.

SIXTH SESSION—MARBURG LECTURE; DUDLEY MEDAL AWARD; RICHARD TEMPLIN AWARD; SAM TOUR AWARD

TUESDAY, JUNE 28, 8:00 P.M.

SESSION CHAIRMAN: PRESIDENT R. L. TEMPLIN

President Templin presented Dr. W. M. Baldwin, Jr., Research Professor and Director, Metals Research Laboratory, Department of Metallurgical Engineering, Case Institute of Technology, Cleveland, Ohio, as the Twenty-third Marburg Lecturer, who then delivered the lecture on "Residual Stresses in Metals." The lecture covered the development of residual stresses. A description of the experimental methods used to evaluate residual stresses, the various residual stress patterns found in fabrication of metals, the effects of residual stresses, and methods for the elimination of resiual stresses were all covered in the lecture.

President Templin, in expressing appreciation to Dr. Baldwin for his very timely and instructive lecture on a subject of particular interest to the A.S. T.M., presented to him, on behalf of the Society, The Edgar Marburg Lecture Certificate.

Medalists and Award Winners:

The Charles B. Dudley Medal, named after the Society's first president and awarded to the author or authors of a paper of outstanding merit constituting an original contribution on research and engineering materials, was presented to W. W. Buechner, R. J. Van de Graaff, H. Feshbach, A. Sperduto, on the staff of Massachusetts Institute of Technology, and E. A. Burril, L. R. McIntosh, formerly on the Staff of M.I.T., now with the High Voltage Engineering Corp., for their paper on "An Investigation of Radiography in the Range from 0.5 to 2.5 Million Volts," published in the December, 1948, issue of the ASTM BULLETIN.

The Richard L. Templin Award, to stimulate research in the development of testing methods and apparatus and to encourage the presentation to the Society of papers describing new and useful testing procedures and apparatus, was given to W. T. Lankford, Research Associate, Research and Technology Dept., Carnegie-Illinois Steel Corp., for his paper on "Hydraulic Bulge Testing of Sheet Metals," presented at the 1948 Annual Meeting and published in the 1948 *Proceedings.*

The first Sam Tour Award, to encourage research on the improvement and evaluation of corrosion testing methods and to stimulate the preparation of technical papers in this field, was given to V. M. Darsey and W. R. Cavanagh, President and Research Chemist, respectively, Parker Rust Proof Co., for their paper on "Apparatus and Factors in Salt Fog Testing," presented at the 1948 Annual Meeting and published in the 1948 *Proceedings.*

SEVENTH SESSION—NON-FERROUS METALS—CORROSION, FATIGUE, ETC.

WEDNESDAY, JUNE 29, 9:30 A.M.

SESSION CHAIRMAN: PRESIDENT R. L. TEMPLIN

Committee B-4 on Electrical Heating, Resistance, and Related Alloys:

Report presented by S. A. Standing, chairman, and the following actions taken:

Adopted as Standard:

Test for Resistivity of Metallically Conducting Resistance and Contact Metals (B 63 – 48 T)

Method for Life Test of Electrical Contact Materials (B 182 – 46 T)

Test for Diameter by Weighing of Fine Wire Used in Electronic Devices and Lamps (B 205 – 45 T)

Committee B-7 on Light Metals and Alloys, Cast and Wrought:

Report presented by I. V. Williams, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Aluminum-Alloy Pipe, with minor corrections in the weights for standard and extra heavy pipes given in Table III.

Accepted as Tentative, Revisions in:

Spec. for Magnesium-Base Alloy Sand Castings (B 80 – 47 T)

Spec. for Magnesium-Base Alloy Sheet (B 90 – 46 T)

Spec. for Magnesium-Base Alloy Forgings (B 91 – 45 T)

Spec. for Magnesium-Base Alloys in Ingot Form for Sand Castings, Die Castings and Permanent Mold Castings (B 93 – 47 T)

Spec. for Magnesium-Base Alloy Bars, Rods and Shapes (B 107 – 48 T)

Spec. for Aluminum and Aluminum-Alloy Sheet and Plate for Use in Pressure Vessels (B 178 – 47 T)

Spec. for Magnesium-Base Alloy Permanent Mold Castings (B 199 – 47 T)

Spec. for Aluminum and Aluminum-Alloy Sheet and Plate (B 209 – 48 T)

Spec. for Aluminum-Alloy Drawn Seamless Tubing (B 210 – 48 T)

Spec. for Aluminum and Aluminum-Alloy Bars, Rods and Wire (B 211 – 48 T)

Spec. for Aluminum and Aluminum-Alloy Extruded Bars, Rods, and Shapes (B 221 – 48 T)

Spec. for Aluminum-Alloy Extruded Tubing (B 235 – 48 T)

Adopted as Standard:

Spec. for Aluminum for Use in Iron and Steel Manufacture (B 37 – 46 T), as revised.

Reaffirmation of Standard:

Spec. for Magnesium Ingot and Stick for Remelting (B 92 – 45)

Committee B-8 on Electrodeposited Metallic Coatings:

Report presented in the absence of the chairman by A. W. Tracy and the following actions taken:

Accepted as Tentative:

Rec. Practice for Preparation of High-Carbon Steel for Electroplating

Accepted as Tentative, Revisions in:

Spec. for Electrodeposited Coatings of Zinc on Steel (A 164 – 40 T)

Spec. for Electrodeposited Coatings of Cadmium on Steel (A 165 – 40 T)

Spec. for Chromate Finishes on Electrodeposited Zinc, Hot-Dipped Galvanized, and Zinc Die-Cast Surfaces (B 201 – 45 T)

Adopted as Standard:

Rec. Practice for Chromium Plating on Steel for Engineering Use (B 177 – 45 T)

Rec. Practice for Preparation of Low-Carbon Steel for Electroplating (B 183 – 43 T)

Attention was called to the incorrect numbering of the three figures in the appended report of Subcommittee II on Performance Tests. To correct this, the figures should be renumbered as follows: Change Fig. 1 to Fig. 3, Fig. 2 to Fig. 1, and Fig. 3 to Fig. 2.

Committee E-7 on Non-Destructive Testing:

Report presented by J. H. Bly, chairman, and the following action taken:

Accepted as Tentative, Revisions in:

Industrial Radiographic Terminology for Use in Radiographic Inspection of Castings and Weldments (E 52 – 45 T)

Committee E-9 on Fatigue:

Report presented by R. E. Peterson, chairman, who called attention to a report on the activities of the Research Subcommittee which had been prepared by its chairman H. F. Moore, but not preprinted with the report.

Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys:

Report presented, in the absence of the chairman, by A. W. Tracy and the following action taken:

Accepted as Tentative, Revisions in:

Method of Salt Spray (Fog) Testing (B 117 – 44 T)

Appendix

Effect of Weather on the Initial Corrosion Rate of Sheet Zinc—O. B. Ellis, presented by the author.

Papers:

Fatigue Characteristics of Aluminum Alloy 75S-T6 Plate in Reversed Bending as Affected by Type of Machine and Specimen—T. T. Oberg and R. J. Rooney, presented by Mr. T. J. Dolan.

Creep and Stress-Rupture Investigations on Some Aluminum Alloy Sheet Metals—J. E. Dorn and T. E. Tietz, presented by Mr. F. M. Howell.

The Influence of Vibration on the Creep of Lead—J. Neill Greenwood, presented by Mr. H. F. Moore.

ROUND TABLE DISCUSSION ON WOOD POLE TESTING

WEDNESDAY, JUNE 29, 9:30 A.M.

SESSION CHAIRMAN: L. G. SMITH

This round table discussion was sponsored by Committee D-7 on Wood in view of its proposed expansion of activities to include the collection of reliable data on the strength of wood poles. This field is of interest to both producers and users of poles because of the persistent difficulty of interpreting test results that have been obtained by varying methods without the benefit of standardized testing procedures. The discussion reviewed a proposed testing program and discussed methods of its implementation.[3a]

EIGHTH AND NINTH SESSIONS—SYMPOSIUM ON TESTING CAST IRON WITH SR-4 TYPE OF GAGE

Eighth Session

WEDNESDAY, JUNE 29, 9:30 A.M.

SESSION CHAIRMAN: J. S. VANICK

Committee A-3 on Cast Iron:

Report presented by C. O. Burgess, secretary, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Automotive Gray Iron Castings (A 159 - 47)

Reaffirmation of Standard:

Spec. for Gray Iron Castings for Valves, Flanges, and Pipe Fittings (A 126 - 42)

Editorial Change Accepted in:

Spec. for Gray Iron Castings (A 48 - 48)

Attention was called to an error under Reaffirmation of Standards where the Standard Specifications for Welded Wrought Iron Pipe (A 72 - 45) had been listed instead of the Standard Specifications for Cast Iron Soil Pipe and Fittings (A 74 - 42).

J. T. MacKenzie presented a report on Impact Testing which is to be appended to the committee report in the *Proceedings*.

Symposium on Testing Cast Iron with SR-4 Type of Gage:[2]

Stress Analysis of Automotive Cylinder Blocks—Martin A. Erickson, presented from manuscript by the author.

Residual Stresses in Cylinder Blocks—R. J. King, presented from manuscript by the author.

An Analysis of Locked-In Stresses in Automotive Cylinder Blocks—S. J. Stockett and H. W. Lownie, Jr., presented from manuscript by Mr. Stockett.

Strain Testing of Crank Shafts, Engine Frames, and Cylinders—H. M. Hardy and T. O. Kuivinen, presented from manuscript by Mr. Kuivinen.

Strain Gage Tests on Diesel Cylinder Blocks, Heads and Pistons—C. L. Newton and J. D. Swannack, presented by title only.

Stress-Strain Tests on Rectangular Cast Iron Beams—Oliver Smalley, presented from manuscript by Mr. E. S. Clark.

Stress-Strain Tests on Various Cast Iron Beam Sections—H. M. Hardy and T. O. Kuivinen, presented from manuscript by Mr. Kuivinen.

Ninth Session

WEDNESDAY, JUNE 29, 1:30 P.M.

SESSION CHAIRMAN: H. BORNSTEIN

Committee E-1 on Methods of Testing:

Report presented by J. R. Townsend, chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for A.S.T.M. Thermometers (E 1 - 48 T)

Adopted as Standard:

Spec. for A.S.T.M. Thermometers (E 1 - 48 T), adoption of the A.S.T.M. Gas Calorimeter Inlet Thermometer (50 F - 47 T) and the Gas Calorimeter Outlet Thermometer (51 F - 47 T)

Adopted as Standard, Revisions in:

Spec. for A.S.T.M. Thermometers (E 1 - 47)

Reaffirmation of Standards:

Spec. for Sieves for Testing Purposes (E 11 - 39)

Hardness Conversion Table for Cartridge Brass (E 33 - 42)

[3a] A detailed article by L. G. Smith covering this program with notes on the discussion will appear in the A.S.T.M. BULLETIN, September, 1949.

Symposium on Testing Cast Iron with SR-4 Type of Gage:[2]

This session was a continuation of the Symposium on Testing Cast Iron with SR-4 Type of Gage. The papers presented at this session are listed below:

Stress Analysis of a Cast Iron 125-lb. Valve Assembly—V. T. Malcolm and S. Low, presented from manuscript by Mr. Low.

Stress Analysis of a Cast Iron Split Tapping Sleeve—E. C. Sears, J. W. Miner, and E. D. McCauley, presented from manuscript by Mr. Miner.

Stress-Strain Analysis of Cast Irons for Valve Parts—Harold Wyatt, presented by title only.

Residual Stresses in Cast Iron Deaerating Trays—J. A. Cameron, presented from manuscript by the author.

Stress Determination in Cast Irons for Railroad Service—Richard A. Flinn and Robert J. Ely, presented from manuscript by Mr. Flinn.

Some Strain Gage Studies of Cast Iron Punch Press Frames—Given A. Brewer, presented from manuscript by Mr. J. S. Vanick.

Location and Measurement of Stresses in Gray Iron Tractor Castings—Hyman Bornstein, presented from manuscript by the author.

Stress-Strain Studies of Cast Iron for Textile Machinery Parts—Victor E. Hillman, presented by title only.

TENTH SESSION—STEEL, FERRO-ALLOYS, EFFECT OF TEMPERATURE

WEDNESDAY, JUNE 29, 1:30 P.M.

SESSION CHAIRMAN: VICE-PRESIDENT J. G. MORROW

Committee E-4 on Metallography:

Report presented by L. L. Wyman, chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Methods of Preparation of Micrographs of Metals and Alloys (Including Recommended Practice for Photography as Applied to Metallography) (E 2 - 44 T)

Reaffirmation of Standards:

Def. of Terms Relating to Metallography (E 7 - 27)

Rec. Practice for Thermal Analysis of Steel (E 14 - 33)

Committee A-7 on Malleable Iron Castings:

Report presented by W. A. Kennedy, chairman.

It was announced that the committee had withdrawn from the report as preprinted, the recommendation for adoption as standard of the Tentative Specifications for Pearlitic Malleable Iron Castings (A 220 - 48 T) and the Tentative Specifications for Malleable Iron Flanges, Pipe Fittings and Valve Parts (A 277 - 44 T), these specifications being continued as tentative.

Committee A-5 on Corrosion of Iron and Steel:

Report presented by T. R. Galloway, chairman, and the following actions taken:

Adopted as Standard:

Test for Weight and Composition of Coating on Long Terne Sheets by the Triple Spot Test (A 309 - 47 T)

Spec. for Zinc Coating (Hot Dip) on Iron and Steel Hardware (A 153 - 47 T), as revised.

It was announced that the committee had withdrawn from the report as preprinted, the proposed revisions in the Standard Method of Test for Uniformity of Coating by the Preece Test (Copper Sulfate Dip) on Zinc-Coated (Galvanized) Iron or Steel Articles (A 239 - 41).

Reaffirmation of Standards:

Spec. for Zinc-Coated (Galvanized) Iron or Steel Telephone and Telegraph Line Wire (A 111 - 43)

Spec. for Zinc-Coated (Galvanized) Iron or Steel Tie Wires (A 112 - 33)

Spec. for Zinc-Coated Iron or Steel Chain-Link Fence Fabric Galvanized After Weaving (A 117 - 33)

Spec. for Zinc-Coated Steel Wire Strand ("Galvanized" and Class A ("Extra Galvanized")) (A 122 - 41)

Spec. for Zinc-Coated Steel Wire Strand (Class B and Class C Coatings) (A 218 - 41)

Test for Weight of Coating on Zinc-Coated (Galvanized) Iron or Steel Articles (A 90 - 39)

Committee A-1 on Steel:

Report presented by N. L. Mochel, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Hot-Rolled Carbon-Steel Bars (A 107 – 47)
Spec. for Cold-Finished Carbon-Steel Bars and Shafting (A 108 – 47)
Spec. for Heat-Treated Carbon- and Alloy-Steel Track Bolts and Nuts (A 183 – 46)

Accepted as Tentative, Revisions in:

Spec. for Structural Steel for Locomotives and Cars (A 113 – 49 T) with a minor revision in Table II consisting of changing the bend test requirement for material over 2 in. in thickness for grade B from the present "2" to read "2½."
Spec. for Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service (A 182 – 48 T)
Spec. for High-Strength Structural Rivet Steel (A 195 – 49 T)
Spec. for Nickel-Steel Plates for Boilers and Other Pressure Vessels (A 203 – 49 T)
Spec. for Chromium-Molybdenum Steel Plates for Boilers and Other Pressure Vessels (A 301 – 49 T)
Spec. for Open-Hearth Carbon-Steel Rails (A 1 – 46)
Spec. for Open-Hearth Carbon-Steel Girder Rails of Plain, Grooved and Guard Types (A 2 – 27)
Spec. for Low-Carbon Steel Joint Bars (A 3 – 46)
Spec. for Medium-Carbon Steel Joint Bars (A 4 – 14)
Spec. for Boiler Rivet Steel and Rivets (A 31 – 40)
Spec. for Soft Steel Track Spikes (A 65 – 33)
Spec. for Steel Screw Spikes (A 66 – 33)
Spec. for Low-Carbon Steel Track Bolts and Nuts (A 76 – 46)
Spec. for Cold-Rolled Strip Steel (A 109 – 38)
Spec. for Carbon-Silicon Steel Plates of Intermediate Tensile Ranges for Fusion-Welded Boilers and Other Pressure Vessels (A 201 – 47)
Spec. for Molybdenum-Steel Plates for Boilers and Other Pressure Vessels (A 204 – 47)
Spec. for High Tensile Strength Carbon-Silicon Steel Plates for Boilers and Other Pressure Vessels (Plates 6 in. and Under in Thickness (A 212 – 47))
Spec. for Manganese-Vanadium Steel Plates for Boilers and Other Pressure Vessels (A 225 – 47)

Adopted as Standard:

Spec. for Minimum Requirements for the Deformations of Deformed Steel Bars for Concrete Reinforcement (A 305 – 47 T); including the following revisions not included in the report as preprinted:[4]

Introduction.—Delete the following from the last sentence: "that the design of the deformation shall provide for a bearing area of the deformations against the concrete, in square inches per lineal inch length of bar when projected on a plane normal to the axis of the bar, of approximately 15 per cent of the nominal size of the bar expressed in inches."

Section 3 (c).—Change to read as follows by the addition of the italicized words: "(*c*) The average spacing or distance between deformations on each side of the bar shall not exceed *seven-tenths of* the nominal size of the bar."

Section 3 (e).—Change to read as follows:

(*e*) The average height of deformations shall not be less than the following percentages of the nominal size of the bar:

Nominal Size of Bar, in.	Minimum Height of Deformations, per cent of Nominal Size of Bar
$\frac{3}{8}$	4
$\frac{1}{2}$	4
$\frac{5}{8}$	4½
$\frac{3}{4}$	5

Table I.—Change to read as given in the accompanying Table I.

Adopted as Standard, Revisions in:

Spec. for Silicon-Manganese Steel Bars for Springs (A 59 – 39), with a minor revision in Table I deleting size ranges "over 6 to 8, incl."
Spec. for Chromium-Vanadium Steel Bars for Springs (A 60 – 42), with the same revision given above for Spec. A 59.
Spec. for Carbon-Steel Bars for Springs with Special Silicon Requirements (A 68 – 44)
Spec. for Forged or Rolled Steel Pipe Flanges for General Service (A 181 – 46)

Withdrawal of Standard:

Spec. for Carbon-Steel Bars for Springs (A 14 – 44)

Joint Committee on Effect of Temperature on the Properties of Metals:

Report presented from manuscript by E. L. Robinson, chairman, and accepted as a report of progress.

Committee A-9 on Ferro-Alloys:

Report presented by W. C. Bowden, Jr., chairman, and accepted as a report of progress.

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[4] This recommendation, not preprinted, was accepted subject to unanimous affirmative letter ballot of Committee A-1, which ballot has been favorable.

TABLE I.—DIMENSIONAL REQUIREMENTS FOR DEFORMED STEEL BARS FOR CONCRETE REINFORCEMENT.

Nominal Size, in.	Cross-Sectional Area, sq. in.	Nominal Diameter, in.	Spacing and Heights of Deformation		Nominal Perimeter, in.	Maximum Gap (Chord of 12½ per cent of Nominal Perimeter), in.
			Maximum Average Spacing, in.	Minimum Height, in.		
1	2	3	4	5	6	7
Rounds:						
⅜	0.11	0.375	0.262	0.015	1.178	0.143
½	0.20	0.500	0.350	0.020	1.571	0.191
⅝	0.31	0.625	0.437	0.028	1.963	0.239
¾	0.44	0.750	0.525	0.038	2.356	0.286
⅞	0.60	0.875	0.612	0.044	2.749	0.334
1	0.79	1.000	0.700	0.050	3.142	0.383
Squares:						
1	1.00	1.000	0.700	0.050	4.00	0.500
1⅛	1.27	1.125	0.787	0.056	4.50	0.562
1¼	1.56	1.250	0.875	0.063	5.00	0.625
Rounds having sections equivalent to sections of the following squares:[a]						
1	1.00	1.128	0.790	0.056	3.544	0.431
1⅛	1.27	1.270	0.889	0.064	3.990	0.487
1¼	1.56	1.410	0.987	0.071	4.430	0.540

[a] Certain rounds are rolled to sections equivalent to the sections of squares. The nominal size shall be taken as th diameter of plain rounds having the same area as the corresponding squares.

Papers:

Elastic Fracture Toughness Studies of Stainless Steel—Carl W. Muhlenbruch, presented by the author.

The Influence of Conditions of Heat Treatment and Hot-Cold Work on the Properties of Low-Carbon N155 Alloy at Room Temperature and 1200 F—J. W. Freeman, E. E. Reynolds, D. N. Frey, and A. E. White, presented by Mr. Reynolds.

Effect of Manufacturing Practice on Creep and Creep-Rupture Strength of Low-Carbon Steel—G. V. Smith and E. J. Dulis, presented by Mr. Smith.

The Effects of Temperature and Material Structure on the Fracture Properties of Medium-Carbon Steel—Julius Miklowitz, presented from manuscript by Mr. M. J. Manjoine.

The Time Delay for the Initiation of Plastic Deformation at Rapidly Applied Constant Stress—D. S. Clark and D. S. Wood, presented by title only.

ELEVENTH SESSION—ELECTRICAL INSULATING MATERIALS, QUALITY CONTROL, TEXTILES, ADHESIVES, FUELS

WEDNESDAY, JUNE 29, 1:30 P.M.

SESSION CO-CHAIRMEN: A. W. GAUGER; PAST-PRESIDENT H. J. BALL

Committee D-3 on Gaseous Fuels:

Report presented by A. W. Gauger, chairman, and accepted as a report of progress.

Committee D-5 on Coal and Coke:

Report presented by W. A. Selvig, chairman, and the following actions taken:

Adopted as Standard:

Drop Shatter Test for Coal (D 440 – 48 T), as revised.

Reaffirmation of Standards:

Spec. for Gas and Coking Coals (D 166 – 24)
Spec. for Classification of Coals by Rank (D 388 – 38)
Spec. for Classification of Coals by Grade (D 389 – 37)
Test for Volume of Cell Space of Lump Coke (D 167 – 24)
Test for Cubic Foot Weight of Crushed Bituminous Coal (D 291 – 29)
Test for Cubic Foot Weight of Coke (D 292 – 29)
Test for Sieve Analysis of Coke (D 293 – 29)
Method of Tumbler Test for Coke (D 294 – 29)
Test for Size of Anthracite (D 310 – 34)
Test for Sieve Analysis of Crushed Bituminous Coal (D 311 – 30)
Sampling Coke for Analysis (D 346 – 35)
Test for Screen Analysis of Coal (D 410 – 38)
Test for Index of Dustiness of Coal and Coke (D 547 – 41)

Def. of Terms Relating to Coal and Coke (D 121 - 30)
Def. for Commercial Varieties of Bituminous and Subbituminous Coals (D 493 - 39)

Committee E-11 on Quality Control of Materials:

Report presented in the absence of the chairman, by W. E. Deming, and accepted as a report of progress.

Committee D-13 on Textile Materials:

Report presented by H. J. Ball, chairman, and the following actions taken:

Accepted as Tentative:

Methods of Core Sampling of Wool in Packages for Determination of Percentage of Hard Scoured Wool Content
Spec. and Methods of Test for Asbestos Lap
Testing Single Kraft Yarn
Test for Stretch of Hosiery
Test for Yarn Number of Yarn from Fabrics

Accepted as Tentative, Revisions in:

Methods of Testing and Tolerances for Cotton Yarns (D 180 - 47 T)
General Methods of Testing Cotton Fibers (D 414 - 47 T)
Methods of Testing and Tolerances for Glass Yarn (D 578 - 47 T)
Test for Resistance of Textile Fabrics and Yarns to Insect Pests (D 582 - 45 T)
Test for Evaluating Compounds Designed to Increase Resistance of Fabrics and Yarns to Insect Pests (D 627 - 41 T)
Rec. Practice for Planning Interlaboratory Testing of Textile Materials (D 990 - 48 T)
Def. of Terms Relating to Textile Materials (D 123 - 48 T)
Spec. and Methods of Test for Asbestos Yarns (D 299 - 48 T)
Methods of Testing Felt (D 461 - 47)
Spec. for Mechanical Roll Felt (D 944 - 49)

Adopted as Standard:

Test for Compatibility of Glass Yarn with Insulating Varnish (D 886 - 46 T)
Spec. for Mechanical Roll Felt (D 944 - 48 T)
Methods for Identification of Fibers in Textiles (D 276 - 43 T), as revised.
Def. of Terms Relating to Textile Materials (D 123 - 48 T), definitions of ten terms

It was announced that the committee had withdrawn from the report as preprinted, the recommendation for adoption as standard of the Tentative Specifications and Methods of Test for Fineness of Wool Tops (D 472 - 47 T) and the Tentative Methods of Test for Fineness of Wool (D 419 - 47 T).

Adopted as Standard, Revisions in:

General Methods of Testing Woven Textile Fabrics (D 39 - 39)
Spec. for Textile Testing Machines (D 76 - 47)
Methods of Testing Felt (D 461 - 47)
Testing and Tolerances for Woven Glass Fabrics (D 579 - 47)
Methods of Testing and Tolerances for Woven Glass Tubular Sleeving and Braids (D 581 - 44)
Methods of Testing and Tolerances for Woven Glass Tapes (D 580 - 47)
Spec. and Methods of Test for Asbestos Tape for Electrical Purposes (D 315 - 44)
Spec. and Methods of Test for Asbestos Roving for Electrical Purposes (D 375 - 44)
Method of Test for Fiber Length of Wool (D 519 - 40)
Methods of Testing and Tolerances for Single Jute Yarn (D 541 - 41)

Withdrawal of Standard and Tentatives:

Test for Strength of Rayon and Estron Woven Fabrics When Wet (D 415 - 38)
Spec. for All Wool, All Cotton, and Wool and Cotton Blanketing (Household) (D 576 - 40 T)
Spec. for Medium-Weight Cotton Corduroy Fabrics (D 625 - 41 T)
Spec. for Finished, All-Cotton, Upholstery Tapestries (D 678 - 42 T)

Reaffirmation of Standards:

Spec. and Methods of Test for Tire Fabrics Other than Cord Fabrics (D 122 - 37)
Spec. and Methods of Test for Certain Heavy Cotton Fabrics for Manufacture of Hose and Belting (D 181 - 42)
Methods of Testing and Tolerances for Certain Light and Medium Weight Cotton Fabrics (D 274 - 36)
Method of Determining Relative Humidity (D 337 - 34)
Methods of Testing and Tolerances for Tubular Sleeving and Braids (D 354 - 41)
Spec. and Methods of Test for Holland Cloth (D 376 - 35)
Methods of Testing Pile Floor Covering (D 418 - 42)
Test for Resistance to Yarn Slippage in Silk, Rayon, and Estron Woven Fabrics (D 434 - 42)
Test for Shrinkage in Laundering of Woven Cotton Cloth (D 437 - 36)
Methods of Testing and Tolerances for Yarns Spun from Mixed Fibers (D 508 - 43)
Methods of Testing Woven Asbestos Cloth (D 577 - 42)

Committee D-12 on Soaps and Other Detergents:

Report presented in the absence of the chairman, by P. J. Smith and the following actions taken:

Adopted as Standard:

Total Immersion Corrosion Test of Water-Soluble Aluminum Cleaners (D 930 – 47 T), as revised
Method of Sampling and Chemical Analysis of Borax (D 501 – 48 T)

Adopted as Standard, Revisions in:

Methods of Sampling and Chemical Analysis of Alkaline Detergents (D 501 – 46)

Editorial Changes Accepted in:

Spec. for Milled Toilet Soap (D 455 – 48)
Spec. for Chip Soap (D 496 – 39)
Spec. for Ordinary Bar Soap (D 497 – 39)
Spec. for Powdered Soap (Nonalkaline Soap Powder) (D 498 – 39)
Spec. for White Floating Toilet Soap (D 499 – 48)
Spec. for Built Soap, Powdered (D 533 – 44)
Spec. for Palm Oil Solid Soap (Type A, Straight; Type B, Blended) (D 535 – 41)
Spec. for Palm Oil Chip Soap (Type A, Straight; Type B, Blended) (D 536 – 42)
Spec. for Olive Oil Solid Soap (Type A, Straight; Type B, Blended) (D 592 – 42)
Spec. for Salt-Water Soap (D 593 – 42)
Spec. for Olive Oil Chip Soap (Type A, Straight; Type B, Blended) (D 630 – 42)
Spec. for Compound Chip Soap (with Rosin) (D 690 – 48)
Spec. for Compound Powdered Soap (Granulated, with Rosin) (D 691 – 44)

Committee D-9 on Electrical Insulating Materials:

Report presented by C. T. Hatcher, chairman, and the following actions taken:

Accepted as Tentative:

Rec. Practice for the Purchase of Uninhibited Mineral Oil for Use in Transformers and in Oil Circuit Breakers
Methods of Testing Glass Bonded Mica Used as Electrical Insulation
Test for the Aqueous Extract Conductivity of Paper Used in Electrical Insulation, to be incorporated as part of Methods D 202
Rec. Practice for Maintaining Constant Relative Humidity by Means of Aqueous Solutions, jointly with Committee D-20

Accepted as Tentative, Revisions in:

Test for Electrical Resistance of Insulating Materials (D 257 – 46)
Spec. for Phenolic Molding Compounds (D 700 – 45 T), jointly with Committee D-20 with an addition to Section 6(*j*) as given under Committee D-20
Spec. for Laminated Thermosetting Materials (D 709 – 48 T), jointly with Committee D-20
Spec. for Vulcanized Fiber Sheets, Rods, and Tubes Used for Electrical Insulation (D 710 – 47 T)
Spec. for Nonrigid Vinyl Chloride Plastics (D 744 – 44 T), subject to concurrence of Committee D-20
Methods of Testing Vulcanized Fiber Used for Electrical Insulation (D 619 – 46 T)
Test for Flexural Properties of Plastics (D 790 – 45 T)
Methods of Testing Varnished Cloths and Varnished Cloth Tapes Used in Electrical Insulation (D 295 – 47 T)
Methods of Sampling and Testing Untreated Paper Used in Electrical Insulation (D 202 – 48 T)
Methods of Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 – 47 T)
Methods of Testing Laminated Tubes Used in Electrical Insulation (D 348 – 46)
Methods of Testing Laminated Round Rods Used in Electrical Insulation (D 349 – 46)

Adopted as Standard:

Spec. for Low and Medium Voltage Pin-Type Lime-Glass Insulators (D 730 – 46 T)
Spec. for Natural Block Mica and Mica Films Suitable for Use in Fixed Mica-Dielectric Capacitors (D 748 – 47 T)
Spec. for Enclosures for Small Testing Machines for Tests at Subnormal and Supernormal Temperatures of Electrical Insulating Materials and Plastics (D 760 – 44 T), jointly with Committee D-20
Spec. for Servicing Units for Tests at Subnormal and Supernormal Temperatures of Electrical Insulating Materials and Plastics (D 761 – 44 T), jointly with Committee D-20
Spec. for Communication and Signal Pin-Type Lime-Glass Insulators (D 879 – 46 T)
Test for Dielectric Strength of Insulating Oil of Petroleum Origin (D 877 – 46 T)
Test for Inorganic Chlorides and Sulfates in Insulating Oil (D 878 – 46 T)
Methods of Sampling Electrical Insulating Oils (D 923 – 47 T)
Test for Power Factor and Dielectric Constant

of Electrical Insulating Oils of Petroleum Origin (D 924 - 47 T)

Adopted as Standard, Revisions in:

Testing Sheet and Plate Materials Used in Electrical Insulation (D 229 - 46), revision of Rockwell hardness method

Testing Pasted Mica Used in Electrical Insulation (D 532 - 39)

Committee D-14 on Adhesives:

Report presented by F. W. Reinhart, chairman, and the following actions taken:

Accepted as Tentative:

Test for Cleavage Strength of Metal-to-Metal Adhesives

Adopted as Standard:

Test for Tensile Properties of Adhesives (D 897 - 46 T)

Test for Peel or Stripping Strength of Adhesives (D 903 - 46 T)

Test for Strength Properties of Adhesives in Shear by Compression Loading (D 905 - 47 T)

Test for Strength Properties of Adhesives in Plywood Type Construction in Shear by Tension Loading (D 906 - 47 T)

It was announced that Committee D-14 had approved by letter ballot, previous to the Annual Meeting, the revision, not preprinted, of the above tentatives being recommended for adoption as standard, to conform with the standard laboratory atmosphere in accordance with that specified in the Tentative Definitions with Procedures Relating to Conditioning and Weathering (A.S.T.M. Designation: E 41).

Committee C-19 on Structural Sandwich Constructions:

Report presented from manuscript by A. G. H. Dietz, chairman, and accepted as a report of progress.

Papers:

Some Problems in the Sampling of Bulk Materials—Louis Tanner and W. Edwards Deming, presented by Mr. Tanner.

Evaluation of Mineral Transformer Oil During Service—Frank M. Clark, presented by Mr. E. A. Snyder.

Fatigue Tests Under Axial Loads of Aluminum Joints Bonded with Cycleweld Adhesive—William N. Findley, Bernard A. Century, and C. P. Hendrickson, presented from manuscript by Mr. Findley.[5]

ANNUAL DINNER

WEDNESDAY, JUNE 29, 7:30 P.M.

Another innovation of the Annual Meeting this year was the absence of any business functions or addresses at the Annual Dinner which was Sponsored by the Philadelphia District. Following an excellent meal there was provided a fine program of entertainment that had been underwritten by members and friends of the Society in the Philadelphia District. Approximately 275 members and guests attended.

TWELFTH SESSION—SYMPOSIUM ON EVALUATION TESTS FOR STAINLESS STEELS

THURSDAY, JUNE 30, 9:30 A.M.

SESSION CHAIRMAN: F. L. LA QUE

Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel, and Related Alloys:

Report presented by Jerome Strauss, chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Corrosion-Resistant Iron-Chromium and Iron-Chromium-Nickel Alloy Castings for General Application (A 296 - 46 T)

Spec. for Heat-Resistant Iron-Chromium and Iron-Chromium-Nickel Alloys for General Application (A 297 - 46 T)

Spec. for Hot-Rolled and Cold-Finished Corrosion-Resisting Steel Bars (A 276 - 44 T), deleting the paragraph relating to tensile strength for types 410, 416, and 430, as preprinted.

Adopted as Standard, Revisions in:

Spec. for Corrosion-Resisting Chromium Steel Plate, Sheet, and Strip (A 176 - 44)

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[5] Publication pending.

Spec. for Corrosion-Resisting Chromium and Chromium Nickel Steel Plate, Sheet, and Strip for Fusion Welded Unfired Pressure Vessels (A 240 – 44), deleting all references pertaining to the addition of a new grade "R," as preprinted.

Symposium on Evaluation Tests for Stainless Steels:[2]

Present Knowledge of Low-Carbon 18-8—H. W. Gillett, presented by Mr. H. C. Cross

Corrosion Resistance and Mechanical Properties of Low-Carbon Austenitic Stainless Steels—D. C. Buck, J. J. Heger, F. J. Phillips, and B. R. Queneau, presented from manuscript by Mr. Buck.

Accelerated Corrosion Testing of Chromium-Nickel Stainless Steel Weldments—F. K. Bloom and M. E. Carruthers, presented from manuscript by Mr. Carruthers.

An Appraisal of Methods for Evaluating the Corrosion Resistance of Stainless Steels—M. H. Brown, W. B. DeLong, and W. R. Myers, presented from manuscript by Mr. Brown.

Some Observations on Tests for Intergranular Susceptibility of 18-8 Mo Stainless Steels—Hilmer Ebling and M. A. Scheil, presented from manuscript by Mr. Ebling.

[*Symposium continued in Fifteenth Session*]

THIRTEENTH SESSION—NON-FERROUS METALS

THURSDAY, JUNE 30, 11 A.M.

SESSION CHAIRMAN: PAST-PRESIDENT J. R. TOWNSEND

Committee B-5 on Copper and Copper Alloys, Cast and Wrought:

Report presented by V. P. Weaver, secretary, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Cartridge Brass Sheet, Strip, Plate, Bar, and Disks (B 19 – 47 T) with a correction in Item 2 of Section 14 (*d*), as preprinted, in which the first part of the sentence is changed to read as follows: "When specific or stock lengths are ordered with ends,"

Spec. for Naval Brass Rods, Bars, and Shapes (B 21 – 48 T)

Spec. for Brass Plate, Sheet, and Strip (B 36 – 48 T)

Spec. for Seamless Copper Tubes (B 75 – 48 T)

Spec. for Leaded Brass Plate, Sheet, and Strip (B 121 – 47 T)

Spec. for Copper-Nickel-Zinc and Copper-Nickel Alloy Plate, Sheet, and Strip (B 122 – 48T) with further revision,[5a] consisting of the substitution of "Copper plus sum of named elements, 99.5 per cent," for "Copper Remainder" for alloys 5, 6, and 7

Spec. for Cartridge Brass Cartridge Case Cups (B 129 – 47 T)

Spec. for Gilding Metal Strip (B 130 – 47 T)

Spec. for Gilding Metal Bullet Jacket Cups (B 131 – 47 T)

Spec. for Copper Rods, Bars, and Shapes (B 133 – 48 T)

Spec. for Miscellaneous Brass Tubes (B 135 – 47 T)

Spec. for Phosphor Bronze Rods, Bars, and Shapes (B 139 – 48 T), further revised[5a] by deletion of "copper remainder" in the table for chemical requirements

Spec. for Aluminum Bronze Rods, Bars, and Shapes (B 150 – 48 T)

Spec. for Copper-Nickel-Zinc Alloy Rods and Bars (B 151 – 48 T)

Spec. for Copper Sheet, Strip, and Plate (B 152 – 48 T)

Spec. for Phosphor Bronze Wire (B 159 – 47 T), further revised[5a] by deletion of "copper remainder" in the table for chemical requirements

Spec. for Aluminum Bronze, Plate, Sheet, and Strip (B 169 – 47 T)

Spec. for Copper Bus Bars, Rods, and Shapes (B 187 – 48 T)

Spec. for Copper Bus Pipes and Tubes (B 188 – 47 T)

Spec. for Beryllium-Copper Alloy Plate, Sheet, and Strip (B 194 – 47 T)

Spec. for Beryllium-Copper Alloy Strip, Special Grade (B 195 – 47 T), further revised[5a] by deletion of footnote *a* in section 4

Spec. for Beryllium-Copper Alloy Rod and Bar (B 196 – 48 T)

Spec. for Beryllium-Copper Alloy Wire (B 197 – 47 T)

Spec. for Copper-Nickel-Zinc Alloy Wire (B 206 – 47 T)

Rec. Practice for Preparing Tension Test Specimens for Copper-Base Alloy Castings (B 208 – 46 T), with a substitution of Fig. 3 of Rec. Practice B 208 – 46 T for Fig. 4 in the revised B 208 as appearing in the preprinted report

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[5a] These recommendations, not preprinted, were accepted subject to confirming letter ballot of committee B-5, which ballot has been favorable.

Spec. for Copper Rods for Locomotive Staybolts (B 12 - 47)
Spec. for Free-Cutting Brass Rod and Bar for Use in Screw Machines (B 16 - 47)
Spec. for Copper-Silicon Alloy Rods, Bars, and Shapes (B 98 - 47)
Spec. for Manganese Bronze Rods, Bars, and Shapes (B 138 - 48)
Spec. for Leaded Red Brass (Hardware Bronze) Rods, Bars, and Shapes (B 140 - 47)

Adopted as Standard:

Spec. for Bronze Castings for Turntables and Movable Bridges and for Bearing and Expansion Plates of Fixed Bridges (B 22 - 47 T), as revised

Adopted as Standard, Revisions in:

Spec. for Copper Plates for Locomotive Fireboxes (B 11 - 47)
Spec. for Copper Rods for Locomotive Staybolts (B 12 - 47)
Spec. for Seamless Copper Boiler Tubes (B 13 - 41)
Spec. for Seamless Brass Boiler Tubes (B 14 - 18)
Spec. for Free-Cutting Brass Rod and Bar for Use in Screw Machines (B 16 - 47)
Spec. for Copper-Base Alloys in Ingot Form for Sand Castings (B 30 - 48)
Spec. for Copper Pipe, Standard Sizes (B 42 - 47)
Spec. for Red Brass Pipe, Standard Sizes (B 43 - 47)
Spec. for Steam or Valve Bronze Castings (B 61 - 46)
Spec. for Composition Brass or Ounce Metal Castings (B 62 - 46)
Spec. for Bronze Castings in the Rough for Locomotive Wearing Parts (B 66 - 46)
Spec. for Car and Tender Journal Bearings, Lined (B 67 - 46)
Spec. for Seamless Copper Tubing, Bright Annealed (B 68 - 47)
Spec. for Copper Water Tube (B 88 - 48) with the revision in Section 15, as preprinted, corrected to read "... '5' to read '7'."
Spec. for Copper-Silicon Alloy Plate and Sheet for Pressure Vessels (B 96 - 47)
Spec. for Copper-Silicon Alloy Plate, Sheet, and Strip for General Purposes (B 97 - 47)
Spec. for Copper-Silicon Alloy Rods, Bars, and Shapes (B 98 - 47)
Spec. for Copper-Silicon Alloy Wire for General Purposes (B 99 - 47)
Spec. for Rolled Copper-Alloy Bearing and Expansion Plates and Sheets For Bridge and Other Structural Uses (B 100 - 47) further revised[5a] by deletion of "copper remainder" for alloy No. 2 in the table for chemical requirements
Spec. for Phosphor Bronze Plate, Sheet, and Strip (B 103 - 47) further revised[5a] by deletion of "copper remainder" in the table for chemical requirements
Spec. for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock (B 111 - 48) with the same revision[5a] for aluminum bronze and copper-nickel alloys as given above for Spec. B 122.
Spec. for Copper and Copper-Base Alloy Forging Rods, Bars, and Shapes (B 124 - 48), with a correction in the table in Section 4 in the nickel content of alloy No. 11b from "4.0 to 11.0" to read "4.0 to 5.5," and the addition of the following: "For alloy No. 12, delete 99.90 in the column headed 'Sum of Named Elements, min., per cent.'" For alloy No. 7, change the zinc limit from "1.7" to read "1.5 max. per cent."
Spec. for Leaded High-Strength Yellow Brass (Manganese Bronze) Sand Castings (B 132 - 48)
Spec. for Brass Wire (B 134 - 48)
Spec. for Manganese Bronze Rods, Bars, and Shapes (B 138 - 48)
Spec. for Leaded Red Brass (Hardware Bronze) Rods, Bars, and Shapes (B 140 - 47)
Spec. for Tin-Bronze and Leaded Tin-Bronze Sand Castings (B 143 - 48)
Spec. for High-Leaded Tin-Bronze Sand Castings (B 144 - 48)
Spec. for Leaded Red Brass and Leaded Semi-Red Brass Sand Castings (B 145 - 48)
Spec. for Leaded Yellow Brass Sand Castings for General Purposes (B 146 - 48)
Spec. for High-Strength Yellow Brass (Manganese Bronze) and Leaded High-Strength Yellow Brass (Leaded Manganese Bronze) Sand Castings (B 147 - 48)
Spec. for Aluminum Bronze Sand Castings (B 148 - 48)
Spec. for Leaded Nickel-Brass (Leaded Nickel-Silver) and Leaded Nickel-Bronze (Leaded Nickel-Silver) Sand Castings (B 149 - 48)
Spec. for Copper-Alloy Condenser Tube Plates (B 171 - 48) with the same revision[5a] for copper-nickel alloy as given above for Spec. B 122. For aluminum bronze, substitute "Copper plus sum of named elements, 99.5 per cent" for "Copper 78.0 min." Delete the requirement "Other impurities 0.5 max., per cent."
Spec. for Silicon-Bronze and Silicon-Brass Sand Castings (B 198 - 48)

The committee recommends the following editorial changes in the report as preprinted:[5a] In the table of physical requirements of Tentative Specifications B 21, B 133, B 139, B 150, B 187, B 196, and of Standard Specifications B 12, B 16, B 98, B 138, and B 140, change "Elongation in 4 × Diameter" to read: "Elongation in 4 × Diameter or Thickness of Specimen," with the footnote changed to read: "In any case a minimum gage length of 1 in. shall be used and in the case of rectangles, the width of the test specimens shall not be more than half the gage length."

Committee B-9 on Metal Powders and Metal Powder Products:

Report presented by W. A. Reich, chairman, and the following action taken:

Accepted as Tentative:

Def. of Terms Used in Powder Metallurgy

Committee B-2 on Non-Ferrous Metals and Alloys:

Report presented by G. H. Le Fevre, secretary, and the following actions taken:

Adopted as Standard:

Spec. for White Metal Bearing Alloys (Known Commercially as "Babbitt Metal") (B 23 – 48 T)

Spec. for Soft Solder Metal (B 32 – 48 T)

Spec. for Fire-Refined Copper for Wrought Products and Alloys (B 216 – 47 T)

Adopted as Standard, Revisions in:

Spec. for Slab Zinc (Spelter) (B 6 – 48)

Spec. for Pig Lead (B 29 – 43)

Reaffirmation of Standards:

Spec. for Lake Copper Wire Bars, Cakes, Slabs, Billets, Ingots, and Ingot Bars (B 4 – 42)

Spec. for Electrolytic Copper Wire Bars, Cakes, Slabs, Billets, Ingots, and Ingot Bars (B 5 – 43)

Spec. for Nickel (B 39 – 22)

Spec. for Rolled Zinc (B 69 – 39)

Spec. for Lead-Coated Copper Sheets (B 101 – 40)

Spec. for Electrolytic Cathode Copper (B 115 – 43)

Committee B-6 on Die-Cast Metals and Alloys:

Report presented by J. R. Townsend, chairman, and the following action taken:

Accepted as Tentative:

Spec. for Zinc-Base Alloys in Ingot Form for Die Castings

Committee B-1 on Wires for Electrical Conductors:

Report presented by W. R. Hibbard, vice-chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Rope-Lay-Stranded Copper Conductors Having Bunch-Stranded Members, for Electrical Conductors (B 172 – 45 T)

Spec. for Rope-Lay-Stranded Copper Conductors Having Concentric-Stranded Members, for Electrical Conductors (B 173 – 47 T)

Spec. for Bunch-Stranded Copper Conductors for Electrical Conductors (B 174 – 45 T)

Spec. for Hard-Drawn Aluminum Wire for Electrical Purposes (B 230 – 48 T), with further revisions in Sections 6(*c*), 8(*b*) (1) and Table I, changing the minimum wire size from "0.0180 in." to "0.0105 in."

Adopted as Standard:

Test for Resistivity of Electrical Conductor Materials (B 193 – 48 T)

Spec. for Cored, Annular, Concentric-Lay-Stranded Copper Conductors (B 226 – 48 T)

Spec. for Concentric-Lay-Stranded Copper Covered Steel Conductors (B 228 – 48 T)

Spec. for Concentric-Lay-Stranded Copper and Copper-Covered Steel Composite Conductors (B 229 – 48 T), with a revision in Section 4 (*a*), changing the maximum length of lay from "18" to "20" times outside diameter.

Spec. for Rolled Aluminum Rods (EC Grade) for Electrical Purposes (B 233 – 48 T)

Spec. for Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft (B 8 – 48 T), as revised

Spec. for Soft Rectangular and Square Bare Copper Wire for Electrical Conductors (B 48 – 48 T), as revised

Spec. for Hard-Drawn Copper-Covered Steel Wire (B 227 – 48 T), as revised

Spec. for Concentric-Lay-Stranded Aluminum Conductors, Hard-Drawn (B 231 – 48 T), as revised

Adopted as Standard, Revisions in:

Spec. for Bronze Trolley Wire (B 9 – 46)

Spec. for Copper Trolley Wire (B 47 – 46)

Spec. for Figure-9 Deep-Section Grooved and Figure-8 Copper Trolley Wire for Industrial Haulage (B 116 – 46)

Spec. for Hard-Drawn Copper Wire (B 1 – 47)

Spec. for Medium-Hard-Drawn Copper Wire (B 2 – 47)

Spec. for Hard-Drawn Copper Alloy Wires for Electrical Conductors (B 105 – 47)

It was announced by the committee that a revision is contemplated of the Tentative Specifications for Concentric-Lay-Stranded Aluminum Conductors, Steel-Reinforced (ACSR) (B 232 - 48 T) through the Administrative Committee on Standards to add a reference to a new tentative for core wire to be submitted concurrently to the Standards Committee.

Committee E-2 on Spectrographic Analysis:

Report presented from manuscript by B. F. Scribner, chairman, and accepted as a report of progress.

FOURTEENTH SESSION—PAINT, NAVAL STORES, WOOD, APPEARANCE

THURSDAY, JUNE 30, 11 A.M.

SESSION CHAIRMAN: VICE-PRESIDENT L. J. MARKWARDT

Committee D-1 on Paint, Varnish, Lacquer, and Related Products:

Report presented by W. T. Pearce, chairman, and the following actions taken:

Accepted as Tentative:

Test for Acetone Number of Heat-Bodied Drying Oils
Test for Bituminous Emulsions Intended for Use as Protective Coatings for Metal
Test for Night Visibility of Traffic Paints
Test for Aniline Point and Mixed Aniline Point of Hydrocarbon Solvents
Test for Total Nitrogen in Resins for Surface Coatings
Method of Conducting Exterior Exposure Tests of Paints on Steel

It was announced that the committee had withdrawn from the report as preprinted, the proposed Tentative Method of Test for Heptane Number of Hydrocarbon Solvents and the Tentative Method of Test for Determination of Kauri-Butanol Number of Hydrocarbon Solvents for further consideration.

Accepted as Tentative, Revisions in:

Test for 60-deg. Specular Gloss of Paint Finishes (D 523 - 48 T)
Methods of Testing Drying Oils (D 555 - 47)

Adopted as Standard:

Spec. for Pure Para Red Toner, Light (D 475 - 48 T)
Spec. for Pure Toluidine Red Toner (D 656 - 48 T)
Spec. for Copper Phthalocyanine Blue (D 963 - 48 T)
Spec. for Aluminum Pigments, Powder and Paste, for Paints (D 962 - 48 T)
Test for Phthalic Anhydride Content of Alkyd Resins and Resin Solutions (D 563 - 47 T)

Adopted as Standard, Revisions in:

Spec. for Dry Bleached Shellac (D 207 - 35)
Spec. for Zinc Yellow (Zinc Chromate) (D 478 - 47)
Methods of Sampling and Testing Lacquer Solvents and Diluents (D 268 - 48)
Spec. for Tricresyl Phosphate (D 363 - 46)

Editorial Changes Accepted in:

Test for Spectral Characteristics and Color of Objects and Materials (D 307 - 44)
Spec. for Acetone (D 329 - 33)
Spec. for Amyl Alcohol (Synthetic) (D 319 - 40)
Spec. for Amyl Acetate (Synthetic) (85 to 88 per cent Grade) (D 318 - 39)
Spec. for Amyl Acetate Made from Fusel Oil (85 to 88 per cent Grade) (D 554 - 39)
Spec. for Butanol (Normal Butyl Alcohol) (D 304 - 45)
Spec. for Normal Butyl Acetate (88 to 92 per cent Grade) (D 303 - 40)
Spec. for Butyl Propionate (90 to 93 per cent Grade) (D 320 - 40)
Spec. for Dibutylphthalate (D 608 - 43)
Spec. for Ethyl Acetate (85 to 88 per cent Grade) (D 302 - 33)
Spec. for Ethyl Lactate (Synthetic) (D 321 - 40)
Spec. for Ethylene Glycol Monoethyl Ether (D 331 - 35)
Spec. for Acetate Ester of Ethylene Glycol Monoethyl Ether (95 to 96 per cent Grade) (D 343 - 35)
Spec. for Ethylene Glycol Monobutyl Ether (D 330 - 35)
Spec. for Isopropyl Acetate (D 657 - 44)
Spec. for Isopropyl Alcohol (D 770 - 46)
Spec. for Methyl Ethyl Ketone (D 740 - 46)

Committee D-7 on Wood:

Report presented by L. J. Markwardt, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Creosoted End-Grain Wood Block Flooring for Interior Use

Spec. for Chromated Zinc Chloride
Spec. for Tanalith
Methods of Chemical Analysis of Chromated Zinc Chloride
Methods of Chemical Analysis of Tanalith
Methods of Static Tests of Wood Poles
Test for Evaluating the Properties of Building Boards
Def. of Terms Relating to Veneer and Plywood

Accepted as Tentative, Revisions in:

Spec. for Creosote-Coal-Tar Solution (D 391 - 36)
Spec. for Zinc Chloride (D 432 - 39)
Methods of Chemical Analysis of Zinc Chloride (D 199 - 27)

Adopted as Standard, Revisions in:

Spec. for Creosote (D 390 - 36)
Test for Distillation of Creosote (D 246 - 42)
Test for Insoluble Matter in Creosote (D 367 - 33)
Methods of Testing Small Clear Specimens of Timber (D 143 - 48)

Committee E-6 on Methods of Testing Building Constructions:

Report presented, in the absence of the chairman, by R. E. Hess, Assistant Executive Secretary, and accepted as a report of progress.

Committee E-12 on Appearance:

Report presented by R. C. Adams, vice-chairman, and accepted as a report of progress.

Committee D-17 on Naval Stores:

Report presented by V. E. Grotlisch, chairman, and the following actions taken:

Accepted as Tentative:

Test for Ash in Rosin
Test for Iron in Rosin
Test for Unsaponifiable Matter in Rosin

Accepted as Tentative, Revisions in:

Methods of Testing Tall Oil (D 803 - 44 T), deleting the revision of Section 31, as preprinted, and changing the revision of Section 30 to read as follows:

Section 30.—In line 2, delete the word "modified," and change the numeral "1" at the end of the formula to "2"; also delete the words "corrected (Note)" in the legend of R_1 and the note at the end of this section.

Test for Acid Number of Rosin (D 465 - 42)
Test for Saponification Number of Rosin (D 464 - 42)

Adopted as Standard:

Methods of Sampling and Testing Pine Oil (D 802 - 46 T), as revised.
Methods of Testing Pine Tar and Tar Oil (D 856 - 46 T), as revised.

Editorial Changes Accepted in:

Methods of Sampling and Grading Rosin (D 509 - 45)

Paper:

Surface Preparation and Repainting of Structural Iron and Steel—Arnold J. Eickhoff, presented from manuscript by the author.

FIFTEENTH SESSION—SYMPOSIUM ON EVALUATION TESTS FOR STAINLESS STEELS

(*Continued from Twelfth Session*)

THURSDAY, JUNE 30, 2 P.M.

SESSION CHAIRMAN: H. L. MAXWELL

Committee A-6 on Magnetic Properties:

Report presented by R. L. Sanford, chairman, and the following actions taken:

Adopted as Standard:

Spec. for Flat-Rolled Electrical Steel (A 310 - 47 T)

Adopted as Standard, Revisions in:

Methods of Testing Magnetic Materials (A 34 - 48), with the following correction in Table I: In the chemical composition for Alnicos 6 and 12, values shown in the Tungsten column are actually titantium contents and should be so designated, with the value for Alnico 12 changed from "3" to "8."

Test for Normal Induction and Hysteresis of Magnetic Materials (A 341 - 49) with the following corrections:

Figure 1.—Revise this figure to eliminate switch 3 and make corresponding editorial changes in the description of the basic circuit in Section 4 (*a*).

Section 5.—In Paragraphs (*c*), (*d*), (*e*), and (*f*), designate the accuracies as "plus or minus" instead of "within."

In Paragraph (*c*) qualify the reference to "methods specified in Table I" by adding "for *H* greater than 1.0 oersted."

In Paragraph (*d*), in the first sentence, add "and excluding spirally wound cores" after the reference to Paragraph (*c*).

Table I.—In the title, change "Appropriate" to "Practicable." In the first column, insert "0.01 to 1.0" opposite "Burrows" and "0.1 to 1.0" opposite "Fahy Simplex." Delete the entire line designated "Full Range." In the last column, opposite "Isthmus" change "1000 and over" to read "1000 to 20,000" with a reference to a footnote *b* which will read: "20,000 obtained with a 1 cm. gap."

Test for Permeability of Feebly Magnetic Materials (A 342 - 49)

Test for Core Loss and Permeability of Magnetic Materials by Alternating Current Procedures (A 343 - 49), changing the title to read "Test for Alternating Current Core Loss and Permeability of Magnetic Materials."

Test for Electrical and Mechanical Properties of Magnetic Materials (A 344 - 49)

Papers:

This session was a continuation of the Symposium on Evaluation Tests for Stainless Steels. The papers presented at this session are listed below:

Influence of Carbon and Molybdenum on the Intergranular Corrosion Resistance of Austenitic Chromium-Nickel Steels With and Without Columbium—W. O. Binder and C. M. Brown, presented from manuscript by Mr. Binder.

Comparative Corrosion Resistance of Stainless Steels in Various Acids—R. B. Mears, C. P. Larrabee, and C. J. Fetner, presented from manuscript by Mr. Larrabee.

Comparison of Plant Corrosion Test Results on Austenitic Stainless Steels with Results of Huey and Strauss Tests—H. O. Teeple, presented from manuscript by the author.

Results of Some Plant Corrosion Tests of Welded Stainless Steels—G. F. Comstock, presented by the author.

Testing Multiple Specimens of Stainless Steels in a Modified Boiling Nitric Acid Test Apparatus—W. B. DeLong, presented from manuscript by the author.

SIXTEENTH SESSION—PLASTICS

THURSDAY, JUNE 30, 2 P.M.

SESSION CHAIRMAN: ROBERT BURNS

Committee D-20 on Plastics:

Report presented by B. L. Lewis, secretary, and the following actions taken:

Accepted as Tentative:

Test for Haze and Luminous Transmittance of Transparent Plastics

Method for Measuring Changes in Linear Dimensions of Plastics

Test for Stiffness Properties of Nonrigid Plastics as a Function of Temperature by Means of a Torsional Test

Test for Resistance of Transparent Plastics to Surface Abrasion, with a change in Section 3 (*a*), as preprinted, revising the loads from "125 to 1000 G." to read "250, 500, or 1000 g." Also in Paragraph (*c*), omit reference to wheel CS-8. Add durometer hardness requirements for wheel CS-10 and CS-10 F. Also add a new Paragraph (*d*) describing the Abraser turntable to "rotate substantially in a plane with a deviation at a distance of 1/16 in. from its periphery of not greater than plus or minus 0.002 in."

Methods of Sampling and Testing Plasticizers Used in Plastics

Rec. Practice for Transfer Molding of Specimens of Phenolic Materials

Rec. Practice for Maintaining Constant Relative Humidity by Means of Aqueous Solutions, jointly with Committee D-9

Accepted as Tentative, Revisions in:

Methods of Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 - 47 T), jointly with Committee D-9 on Electrical Insulating Materials

Test for Tensile Properties of Plastics (D 638 - 46 T)

Spec. for Molds for Test Specimens of Molding Materials Used for Electrical Insulation (D 647 - 45 T)

Test for Repeated Flexural Stress (Fatigue) of Plastics (D 671 - 42 T)

Test for Compressive Strength of Plastics (D 695 - 44 T)

Spec. for Phenolic Molding Compounds (D 700 - 45 T), jointly with Committee D-9, with the addition of the following clause to Section 6 (*j*) as preprinted: "and conditioned in accordance with Procedure C of A.S.T.M. Method D 618 (90 per cent relative humidity at 35 C. for 96 hr.), and measured while still in the conditioned atmosphere. The voltage applied to the electrodes shall be 100 v. D-C. 1 min. after application of voltage."

Spec. for Polystyrene Molding Compounds (D 703 - 48 T)

Spec. for Laminated Thermosetting Materials (D 709 - 48 T), jointly with Committee D-9

Test for Flexural Properties of Plastics (D 790 - 45 T), jointly with Committee D-9

Def. of Terms Relating to Plastics (D 883 - 46 T), including only Part I, Definitions of Terms Relating to Plastics. Further consideration is being given to Part II, Code for Designating Form of Specimen and Direction of Testing Plastics, for publication as a tentative recommended practice.

Adopted as Standard:

Spec. for Cellulose Nitrate (Pyroxylin) Plastic Sheets, Rods, and Tubes (D 701 - 46 T)

Spec. for Enclosures for Small Testing Machines for Tests at Subnormal and Supernormal Temperatures of Electrical Insulating Materials and Plastics (D 760 - 44 T), jointly with Committee D-9

Spec. for Servicing Units for Tests at Subnormal and Supernormal Temperatures of Electrical Insulating Materials and Plastics (D 761 - 44 T), jointly with Committee D-9

Spec. for Cellulose Acetate Plastic Sheets (D 786 - 46 T)

Test for Colorfastness of Plastics to Light (D 620 - 45 T)

Test for Flammability of Plastics, Self-Extinguishing Type (D 757 - 44 T)

Test for Short-Time Stability at Elevated Temperatures of Plastics Containing Chlorine (D 793 - 44 T)

Test for Acetyl and Butyryl Content of Cellulose Acetate Butyrate (D 817 - 44 T)

Test for Ammonia in Phenol-Formaldehyde Molded Materials (D 834 - 45 T), as revised.

Rec. Practice for Determining Permanent Effect of Heat on Plastics (D 794 - 44 T)

Rec. Practice for Accelerated Weathering of Plastics Using S-1 Bulb and Fog Chamber (D 795 - 44 T)

Rec. Practice for Molding Specimens of Phenolic Materials for Use in Electrical Tests (D 949 - 47 T)

Rec. Practice for Molding Specimens of Phenolic Materials (D 796 - 48 T), as revised.

Adopted as Standard, Revisions in:

Spec. for Urea-Formaldehyde Molding Compounds (D 705 - 46)

Reaffirmation of Standards:

Test for Flammability of Plastics 0.050 in. and Under in Thickness (D 568 - 43)

Test for Surface Irregularities of Flat Transparent Plastic Sheet (D 637 - 43)

Papers:

Impact Testing of Plastics—Elimination of the Toss Factor—Bryce Maxwell and L. F. Rahm, presented by Mr. Maxwell.[6]

Flexure Testing of Plastic Materials—J. W. Westwater, presented by the author.

Damping and Resonant Load-Carrying Capacities of Polystyrene and Other High Polymers—J. A. Sauer and W. J. Oliphant, presented by Mr. Sauer.

The Creep Characteristics of Compression Molded Polyethylene—G. R. Gohn, J. D. Cummings, and W. C. Ellis, presented by Mr. Gohn.

Five Plastic Laminates Under Fatigue, Creep, and Static Loads—William N. Findley and W. J. Worley, presented from manuscript by Mr. Findley.[6]

The Effect of Temperature on the Creep and Recovery of a Glass Fabric Laminate Molded with a Melamine Resin—William J. Worley and W. N. Findley, presented from manuscript by Mr. Findley.[6]

Creep-Time Relations for Polystyrene Under Tension, Bending, and Torsion—J. Marin and G. E. Cuff, presented by Mr. Marin.

SEVENTEENTH SESSION—SYMPOSIUM ON ACCELERATED DURABILITY TESTING OF BITUMINOUS MATERIALS

THURSDAY, JUNE 30, 2 P.M.

SESSION CHAIRMAN: C. A. CARPENTER

Committee D-4 on Road and Paving Materials:

Report presented by F. H. Baumann, chairman, and the following actions taken:

It was announced that the committee concurred with Committee C-9, in recommending the publication as tentative of the Method of Test for Soft Particles in Coarse Aggregates, appended to the Report of Committee C-9.

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[6] Published in ASTM BULLETIN, No. 161, October, 1949, p. 44.

Accepted as Tentative, Revisions in:

Methods of Sampling Bituminous Materials (D 140 - 48 T)
Spec. for Hot-Mixed, Hot-Laid Asphaltic Concrete for Base and Surface Courses (D 947 - 48 T)
Spec. for Asphaltic Mixtures for Sheet Asphalt Pavements (D 978 - 48 T)
Methods of Sampling Bituminous Paving Mixtures (D 979 - 48 T)
Spec. for Bituminous Paving Plant Requirements (D 995 - 48 T)
Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (C 131 - 47), jointly with Committee C-9 on Concrete and Concrete Aggregates
Def. of Terms Relating to Materials for Roads and Pavements (D 8 - 46)

Adopted as Standard:

Spec. for Emulsified Asphalt (D 977 - 48 T)
Test for Moisture-Density Relations of Soils (D 698 - 42 T), subject to approval of Committee D-18 on Soils for Engineering Purposes
Test for Penetration of Bituminous Materials (D 5 - 47 T), as revised.
Test for Hot Extraction of Asphaltic Materials and Recovery of Bitumen by the Modified Abson Procedure (D 762 - 47 T), as revised.

Adopted as Standard, Revisions in:

Def. of Terms Relating to Materials for Roads and Pavements (D 8 - 46)
Test for Amount of Material Finer Than No. 200 Sieve in Aggregates (C 117 - 48), jointly with Committee C-9
Method of Float Test for Bituminous Materials (D 139 - 27)
Test for Distillation of Cut-Back Asphaltic Products (D 402 - 48), changing the addition of the note from Section 7 (*e*) to Section 1.
Spec. for Standard Sizes of Coarse Aggregate for Highway Construction (D 448 - 47)
Spec. for Crushed Stone, Crushed Slag, and Gravel for Bituminous Concrete Base and Surface Courses of Pavements (D 692 - 47)
Spec. for Crushed Stone and Crushed Slag for Bituminous Macadam Base and Surface Courses of Pavements (D 693 - 44)
Spec. for Crushed Stone, Crushed Slag, and Gravel for Water-Bound Macadam Base and Surface Courses of Pavements (D 694 - 44)
Methods of Testing Emulsified Asphalts (D 244 - 42), jointly with Committee D-8 on Bituminous Waterproofing and Roofing Materials
Spec. for Preformed Expansion Joint Fillers for Concrete (Nonextruding and Resilient Types, (D 544 - 48)
Methods of Testing Preformed Expansion Joint Fillers for Concrete (Nonextruding and Resilient Types) (D 545 - 48)

Withdrawal of Standards:

Test for Penetration of Bituminous Materials (D 5 - 25)
Spec. for Medium-Setting Emulsified Asphalt (for Retread and Coarse Aggregate Mixes) (D 398 - 39)
Spec. for Medium-Setting Emulsified Asphalt (Heavy Premix-Summer Grade) (D 399 - 39)
Spec. for Quick-Setting Emulsified Asphalt (for Penetration and Surface Treatment) (D 401 - 40)
Spec. for Slow-Setting Emulsified Asphalt (for Fine Aggregate Mixes) (D 631 - 46)
Spec. for Sand for Sheet Asphalt and Bituminous Concrete Pavements (D 162 - 29)
Spec. for Medium-Setting Emulsified Asphalt (for Coarse Aggregate Plant Mixes) (D 397 - 39)

Reaffirmation of Standards:

Test for Abrasion of Rock by Use of the Deval Machine (D 2 - 33)
Test for Toughness of Rock (D 3 - 18)
Test for Distillation of Tar Products Suitable for Road Treatment (D 20 - 30)
Test for Softening Point of Bituminous Materials (Ring-and-Ball Method) (D 36 - 26)
Test for Softening Point of Tar Products (Cube-in-Water Method) (D 61 - 38)
Test for Specific Gravity of Road Oils, Road Tars, Asphalt Cements, and Soft Tar Pitches (D 70 - 27)
Test for Specific Gravity of Asphalts and Tar Pitches Sufficiently Solid to be Handled in Fragments (D 71 - 27)

Editorial Changes Accepted in:

Test for Softening Point of Bituminous Materials (Ring-and-Ball Method) (D 36 - 26)
Test for Softening Point of Tar Products (Cube-in-Water Method) (D 61 - 38)
Test for Ductility of Bituminous Materials (D 113 - 44)

Committee D-8 on Bituminous Waterproofing and Roofing Materials:

Report presented by E. E. Berger, vice-chairman, and the following actions taken:

Adopted as Standard:

Spec. for Asphalt for Dampproofing and Waterproofing (D 449 - 47 T)
Spec. for Coal-Tar Pitch for Steep Built-Up Roofs (D 654 - 42 T)
Methods of Sampling Bituminous Materials

(D 140 - 48 T), as revised, subject to approval of Committee D-4

Adopted as Standard, Revisions in:

Methods of Testing Emulsified Asphalts (D 244 - 42), jointly with Committee D-4

Reaffirmation of Standards:

Spec. for Primer for Use with Asphalt in Dampproofing and Waterproofing (D 41 - 41)
Spec. for Creosote for Priming Coat with Coal-Tar Pitch in Dampproofing and Waterproofing (D 43 - 41)
Spec. for Coal-Tar Pitch for Roofing, Dampproofing, and Waterproofing (D 450 - 41)
Spec. for Asphalt Mastic for Use in Waterproofing (Asphalt Cement, Mineral Filler, Mineral Aggregate) (D 491 - 41)
Spec. for Bituminous Grout for Use in Waterproofing Above Ground Level (D 170 - 41)
Spec. for Bituminous Grout for Use in Waterproofing Below Ground Level (D 171 - 41)
Methods of Testing Bituminous Mastics, Grouts, and Like Mixtures (D 147 - 41)
Test for Steam Distillation of Bituminous Protective Coatings (D 255 - 28)
Test for Sieve Analysis of Granular Mineral Surfacing for Asphalt Roofing and Shingles (D 451 - 40)
Test for Sieve Analysis of Nongranular Mineral Surfacing for Asphalt Roofing and Shingles (D 452 - 40)
Testing Films Deposited from Bituminous Emulsions (D 466 - 42)
Test for Coarse Particles in Mixtures of Asphalt and Mineral Matter (D 313 - 41)

Editorial Changes Accepted in:

Spec. for Bituminous Grout for Use in Waterproofing Above Ground Level (D 170 - 41)
Spec. for Bituminous Grout for Use in Waterproofing Below Ground Level (D 171 - 41)
Test for Coarse Particles in Mixtures of Asphalt and Mineral Matter (D 313 - 41)
Spec. for Asphalt Roofing Surfaced with Powdered Talc or Mica (D 224 - 46 T)

Symposium on Accelerated Durability Testing of Bituminous Materials:[2]

A Review of Accelerated Test Methods for the Evaluation of Road Tars—E. O. Rhodes, presented from manuscript by the author.
Characteristics of Carbon Arc Light Sources for Accelerated Exposure Testing—W. W. Lozier, M. R. Null, and F. T. Bowditch, presented from manuscript by Mr. Lozier.
Behavior of Bituminous Road Materials Under Accelerated Exposure Conditions and Laboratory Heat Tests—Richard H. Lewis, presented from manuscript by the author.
Accelerated Weathering of Road Tars—E. W. McGovern, presented from manuscript by the author.
Immersion-Compression Tests Compared with Laboratory Traffic Tests on Bituminous Concrete—A. T. Goldbeck, presented from manuscript by the author.
The Use of an Abrasion Test as a Measure of Durability of Bituminous Mixtures—John H. Swanberg and W. L. Hindermann, presented from manuscript by Mr. Swanberg.
Test Methods for Performing Accelerated Durability Tests on Asphalts—T. E. Stanton, presented from manuscript by Mr. V. H. Endersby.

[*Symposium Continued in Twentieth Session*]

EIGHTEENTH SESSION—CONCRETE, THERMAL INSULATING MATERIALS

THURSDAY, JUNE 30, 8 P.M.

SESSION CHAIRMAN: A. T. GOLDBECK

Committee C-7 on Lime:

Report presented by W. C. Voss, chairman, and the following actions taken:

Adopted as Standard:

Spec. for Normal Finishing Hydrated Lime (C 6 - 46 T)
Spec. for Special Finishing Hydrated Lime (C 206 - 46 T)
Spec. for Hydrated Lime for Masonry Purposes (C 207 - 46 T)
Methods of Physical Testing of Quicklime and Hydrated Lime (C 110 - 45 T)

Reaffirmation of Standards:

Spec. for Quicklime for Structural Purposes (C 5 - 26)
Spec. for Sand for Use in Plaster (C 35 - 39)
Spec. for Quicklime and Hydrated Lime for Cooking of Rags in Paper Manufacture (C 45 - 25)
Spec. for Quicklime for Sulfite Pulp Manufacture (C 46 - 27)
Spec. for Hydrated Lime for Varnish Manufacture (C 47 - 27)
Spec. for Quicklime and Hydrated Lime for Use in the Textile Industry (C 48 - 24)

Spec. for Quicklime and Hydrated Lime for Silica Brick Manufacture (C 49 - 42)
Spec. for Quicklime and Hydrated Lime for Water Treatment (C 53 - 39)
Spec. for Hydraulic Hydrated Lime for Structural Purposes (C 141 - 42)
Methods of Sampling, Inspection, Packing, and Marking of Quicklime and Lime Products (C 50 - 27)

Committee C-16 on Thermal Insulating Materials:

Report presented by B. A. Hollenbeck, vice-chairman, and the following actions taken:

Accepted as Tentative:

Test for Thermal Conductance and Transmittance of Built-Up Sections by Means of the Guarded Hot Box Method

Editorial Changes Accepted in:

Spec. for 85 per cent Magnesia Thermal Insulating Cement (C 193 - 48)
Spec. for Asbestos Thermal Insulating Cement (C 194 - 48)
Spec. for Mineral Wool Thermal Insulating Cement (C 195 - 48 T)
Spec. for Expanded or Exfoliated Vermiculite Thermal Insulating Cement (C 196 - 48)
Spec. for Diatomaceous Silica Thermal Insulating Cement (C 197 - 48)
Methods of Sampling and Mixing Thermal Insulating Cement (C 163 - 44)

Committee C-9 on Concrete and Concrete Aggregates:

Report presented by K. B. Woods, chairman, and the following actions taken:

Accepted as Tentative:

Test for Bleeding of Concrete
Test for Air Content of Freshly Mixed Concrete by the Pressure Method
Test for Air-Entraining Admixtures for Concrete
Test for Comparing Concretes on the Basis of the Bond Developed with Reinforcing Steel
Test for Soft Particles in Coarse Aggregates, jointly with Committee D-4

Accepted as Tentative, Revisions in:

Spec. for Waterproof Paper for Curing Concrete (C 171 - 42 T)
Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (C 131 - 47), jointly with Committee D-4

Adopted as Standard:

Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory (C 192 - 47 T), as revised, with the following editorial corrections:

Section 9.—Delete the words "For relatively dry mixes" from the preprinted revision of this section.

Section 12.—Correct the revised sentence, as preprinted, to read: "The cross-section of the flexure test specimens shall be not less than 6 by 6 in. for coarse aggregate 2 in. and under in nominal size."

Adopted as Standard, Revisions in:

Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Field (C 31 - 44)
Methods of Securing, Preparing and Testing Specimens from Hardened Concrete for Compressive and Flexural Strength (C 42 - 44)
Test for Flexural Strength of Concrete (Using Simple Beam With Third-Point Loading, (C 78 - 44)
Test for Compressive Strength of Concrete Using Portions of Beams Broken in Flexure (C 116 - 44)
Spec. for Concrete Aggregates (C 33 - 46)
Test for Compressive Strength of Molded Concrete Cylinders (C 39 - 44)
Test for Amount of Material Finer than No. 200 Sieve in Aggregates (C 117 - 48), jointly with Committee D-4
Method of Measuring Length of Drilled Concrete Cores (C 174 - 44)

Withdrawal of Standard:

Spec. for Sodium Silicate for Curing Concrete (C 111 - 36)

Reaffirmation of Standards:

Test for Unit Weight of Aggregate (C 29 - 42)
Test for Voids in Aggregate for Concrete (C 30 - 37)
Test for Cement Content of Hardened Portland-Cement Concrete (C 85 - 42)
Test for Flow of Portland-Cement Concrete by Use of the Flow Table (C 124 - 38)
Test for Specific Gravity and Absorption of Coarse Aggregate (C 127 - 42)
Test for Specific Gravity and Absorption of Fine Aggregate (C 128 - 42)
Test for Clay Lumps in Aggregates (C 142 - 39)
Slump Test for Consistency of Portland-Cement Concrete (C 143 - 39)
Test for Volume Change of Cement Mortar and Concrete (C 157 - 43)

Spec. for Lightweight Aggregates for Concrete (C 130 - 42)

Accepted for Publication as Information Only:

Def. of the Term Chert

Sanford E. Thompson Award:

Mr. Woods then presented the eighth Sanford E. Thompson Award to Leslie P. Witte, co-author with Richard C. Mielenz, Materials Engineer and Head Petrographic Laboratory, respectively, Bureau of Reclamation, United States Department of Interior, for their paper on "Tests Used by the Bureau of Reclamation for Identifying Reactive Concrete Aggregates," published in the 1948 *Proceedings*. Mr. Witte expressed appreciation for both himself and Mr. Mielenz who was unable to be present. This award was established in 1938 by Committee C-9 on Concrete and Concrete Aggregates as an annual token of recognition to the author or authors of a paper of outstanding merit on concrete and concrete aggregates presented at an annual meeting of the Society.

Papers:

A Wetting and Drying Test for Predicting Cement-Aggregate Reaction—C. H. Scholer, presented by the author.

Chemical Reactions of Indiana Aggregate in Disintegration of Concrete—Floyd O. Slate, presented by the author.

Engineering Properties of Coral Reef Materials —C. Martin Duke, presented by the author.

The Preparation of Concrete for Airport Runways—Inge Lyse, presented from manuscript by the author.[7]

The Design of Concrete Mixes Containing Entrained Air—Thomas H. Thornburn, brief summary of paper presented by Mr. D. L. Bloem.

NINETEENTH SESSION—ROUND-TABLE DISCUSSION ON STANDARDS FOR WATER-BORNE WASTES

THURSDAY, JUNE 30, 8 P.M.

SESSION CO-CHAIRMEN: R. C. ADAMS AND L. K. HERNDON

Committee D-19 on Industrial Water:

Report presented by Max Hecht, chairman, and the following actions taken:

Accepted as Tentative:

Method of Sampling Steam

Test for Acidity and Alkalinity in Industrial Water

Test for Suspended and Dissolved Solids in Industrial Water

Test for Iron in Industrial Water

Accepted as Tentative, Revisions in:

Test for Dissolved Oxygen in Industrial Water (D 888 - 46 T), with a modification in the revised Fig. 1 to bring the dimensions into agreement with good glass-blowing practice and an editorial change in Section 5 (*h*) adding the following note:

Note.—The end point may also be detected by means of "dead-stop" titration apparatus.

Add a footnote reference in the above note to the paper by R. C. Ulmer, J. M. Reynar, and J. M. Decker on "Applicability of the Schwartz-Gurney Method for Determining Dissolved Oxygen in Boiler Feedwater and Modification of the Method to Make It Especially Applicable in the Presence of Such Impurities as Are Encountered in Power Plants," published in the 1943 *Proceedings*.

Adopted as Standard:

Methods of Sampling Water for Industrial Uses (D 510 - 47 T), as revised

Test for Tendency of Boiler Water to Cause Embrittlement Cracking of Steel (D 807 - 48 T), as revised

Corrosion Tests in Industrial Waters (NDHA Method) (D 935 - 48 T), as revised

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[7] Published in ASTM BULLETIN, No. 161, October, 1949, p. 48.

Test for Manganese in Industrial Waters (D 858 - 48 T)

Field Sampling of Water-Formed Deposits (D 887 - 48 T)

Method of Reporting Results of Chemical Analysis of Water-Formed Deposits (D 933 - 47 T)

Adopted as Standard, Revisions in:

Method for Determination of the Chloride Ion in Industrial Waters (D 512 - 42)

Method for Determination of the Sulfate Ion in Industrial Waters (D 516 - 42)

Method of Reporting Results of Analysis of Industrial Waters (D 596 - 46)

Round Table Discussion on Need for Standards for Examination of Water-Borne Industrial Wastes:[8]

The Need for Standards for the Inspection of Water-Borne Industrial Wastes—L. Kermit Herndon, presented from manuscript by the author.

Gaging and Sampling of Water-Borne Industrial Wastes—C. F. Hauck, presented from manuscript by Mr. Hauck.

Analysis of Water-Borne Industrial Wastes—George D. Beal and S. A. Braley, presented from manuscript by Mr. Braley.

Sound Film in Color "Air, Water, and Industry,"—Presented by Dow Chemical Co.

TWENTIETH SESSION—SYMPOSIUM ON ACCELERATED DURABILITY TESTING OF BITUMINOUS MATERIALS (*continued from Seventeenth Session*)

FRIDAY, JULY 1, 9:30 A.M.

SESSION CHAIRMAN: W. F. FAIR, JR.

This session was a continuation of the Symposium on Accelerated Durability Testing of Bituminous Materials.[2] The papers presented at this session are listed below:

Durability Tests—A Word of Caution—G. L. Oliensis, presented from manuscript by the author.

Accelerated Weathering of Pitches and Asphalts—W. F. Fair, Jr., H. R. Beck, and B. K. McKee, presented from manuscript by Mr. Fair.

Mineral Stabilizers in Asphalt Roofings—L. Kirshbraun, R. H. Cubberley, and F. W. Yeager, presented from manuscript by Mr. Yeager.

A New Photographic Method for Evaluating Failure of Bituminous Materials Due to Weathering—J. B. Hunter, F. C. Gzemski, and L. Laskaris, presented from manuscript by Mr. Hunter.

The Design and Application of a Spark-Gap Instrument for Detecting Crack Failures of Asphalt Coatings During Weathering Tests—A. H. Boenau and L. A. H. Baum, presented from manuscript by Mr. Boenau.

Experience with Radiation in Accelerated Durability Tests on Bituminous Materials—Joseph Zapata, presented from manuscript by the author.

20 to 30 Years' Weathering of Asphalt Shingles Made with Unfilled Coatings—G. L. Oliensis—presented by the author.[9]

TWENTY-FIRST SESSION—PETROLEUM PRODUCTS, RUBBER, ENGINE ANTIFREEZES, HYDROCARBONS, SHIPPING MATERIALS

FRIDAY, JULY 1, 2 P.M.

SESSION CHAIRMAN: PAST-PRESIDENT A. W. CARPENTER

Committee D-2 on Petroleum Products and Lubricants:

Report presented by O. L. Maag, vice-chairman, and the following actions taken:

Accepted as Tentative:

Test for Acetylene in Polymerization Grade

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[8] Published in ASTM BULLETIN, No. 162, December, 1949, p. 35.

[9] Publication pending.

Butadiene by Silver Nitrate Method

Test for Oxygen in Butadiene Vapors by Manganous Hydroxide Method

Test for Peroxides in Butadiene by Ferrous-Titanous Method

Test for Separation of Residue from Butadiene

Test for Butadiene Dimer in Polymerization Grade Butadiene

Test for Nonvolatile Residue of Polymerization Grade Butadiene

Test for Sodium in Lubricating Oils and Lubricating Oil Additives

Test for Measurement of Freezing Points for Evaluation of Purity

Test for Determination of Purity from Freezing Points

Test for Hydrogen in Petroleum Fractions by the Lamp Method

Test for Olefinic Plus Aromatic Hydrocarbons in Petroleum Distillates

Test for Benzene and Toluene by Ultraviolet Spectrophotometry, with the addition of the following new Section 13 on Precision, not preprinted:[10]

13. *Precision.*—Results should not differ from the mean by more than the following amounts:

Concentration Range for Benzene and Toluene, per cent by weight	Repeatability (One Operator and Apparatus)	Reproducibility (Different Operators and Apparatus)
0.5 to 2	0.05	0.10
2 to 10	0.10	0.25
10 to 15	0.20	0.40
15 to 20	0.25	0.50
20 to 25	0.30	0.60

Accepted as Tentative, Revisions in:

Spec. for Gasoline (D 439 – 48 T)

Test for Rust-Preventing Characteristics of Steam Turbine Oil in the Presence of Water (D 665 – 47 T)

Test for Knock Characteristics of Aviation Fuels by the Aviation Method (D 614 – 48 T)

Test for Oil Content of Paraffin Wax (D 721 – 47)

Test for Knock Characteristics of Motor Fuels by the Research Method (D 908 – 48 T)

Test for Knock Characteristics of Aviation Fuels by the Supercharge Method (D 909 – 48 T)

Test for Penetration of Petrolatum (D 937 – 47 T)

Test for Aromatic Hydrocarbons in Olefin-Free Gasolines by Silica Gel Adsorption (D 936 – 47 T)

Test for Detection of Free Sulfur and Corrosive Sulfur Compounds in Gasoline (D 130 – 30), in the form of a new tentative method with the following changes not preprinted:[7] In Section 4 (*b*) change "$\frac{1}{8}$-in. thick" to read "$\frac{1}{16}$ to $\frac{1}{8}$ in. thick"; in Section 6 (*a*), change "50 ml." to read "30 ml."; in Section 6 (*a*) and (*b*), change "3 hr. to 3 hr. and 15 min." to read "3 hr. ± 5 min." Also all temperatures will be expressed in degrees Fahrenheit, followed by equivalent Centigrade values.

Adopted as Standard:

Test for Burning Quality of Kerosine (D 187 – 47 T)

Test for Neutralization Value (Acid and Base Numbers by Electrometric Titration, (D 664 – 46 T)

Test for Oxidation Stability of Aviation Gasoline (Potential Gum Method) (D 873 – 46 T), as revised

Test for Congealing Point of Pharmaceutical Petrolatums (D 938 – 47 T)

Method of Measurement of Density of Hydrocarbon Liquids by the Pycnometer (D 941 – 47 T)

The committee withdrew from the report as preprinted, the recommendation for adoption as standard of the Tentative Method of Test for Water and Sediment in Petroleum Products by Means of Centrifuge (D 96 – 47 T) and the revisions of the Tentative Method of Test for Kinematic Viscosity (D 445 – 46 T).

Adopted as Standard, Revisions in:

Test for Existent Gum in Gasoline (Air-Jet Evaporation Method) (D 381 – 46)

Test for Oxidation Stability of Gasoline (Induction Period Method) (D 525 – 46)

Test for Vapor Pressure of Petroleum Products (Reid Method) (D 323 – 43)

Test for Knock Characteristics of Motor Fuels by the Motor Method (D 357 – 48)

Test for Melting Point of Petrolatum (D 127 – 30)

Test for Color of Refined Petroleum Oil by Means of Saybolt Chromometer (D 156 – 38)

Test for Sulfur in Petroleum Oils by Bomb Method (D 129 – 44)

Def. of Terms Relating to Petroleum (D 288 – 48)

Withdrawal of Tentative Methods:

Test for Sulfur in Lubricating Oils (D 894 – 48 T)

Test for Determination of Purity by Measurement of Freezing Points (D 940 – 47 T)

Withdrawal of Standard:

Test for Acid Heat of Gasoline (D 481 – 39)

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[10] This addition was approved, subject to confirming letter ballot of Committee D-2, but since a favorable vote was not obtained, this additional change was not accepted.

Reaffirmation of Standards:

Spec. for Stoddard Solvent (D 484 - 40)
Test for Flash Point by Means of the Tag Closed Tester (D 56 - 36)
Test for Melting Point of Paraffin Wax (D 87 - 42)
Test for Precipitation Number of Lubricating Oils (D 91 - 40)
Test for Color of Refined Petroleum Oil by Means of Saybolt Chromometer (D 156 - 38)
Test for Steam Emulsion of Lubricating Oils (D 157 - 36)
Test for Distillation of Gas Oil and Similar Distillate Fuel Oils (D 158 - 41)
Abridged Volume Correction Table for Petroleum Oils (D 206 - 36)
Test for Distillation of Natural Gasoline (D 216 - 40)
Test for Burning Quality of Long-Time Burning Oil for Railway Use (D 219 - 36)
Test for Burning Quality of Mineral Seal Oil (D 239 - 30)
Test for Thermal Value of Fuel Oil (D 240 - 39)
Test for Distillation of Crude Petroleum (D 285 - 41)
Test for Autogenous Ignition Temperatures of Petroleum Products (D 286 - 30)
Test for Gravity of Petroleum and Petroleum Products by Means of the Hydrometer (D 287 - 39)
Test for Dilution of Crankcase Oils (D 322 - 35)
Standard Viscosity-Temperature Charts for Liquid Petroleum Products (D 341 - 43)
Conversion of Kinematic Viscosity to Saybolt Universal Viscosity (D 446 - 39)
Test for Distillation of Plant Spray Oils (D 447 - 41)
Test for Unsulfonated Residue of Plant Spray Oils (D 483 - 40)
Test for Carbon Residue of Petroleum Products (Ramsbottom Carbon Residue) (D 524 - 42)
Test for Dropping Point of Lubricating Grease (D 566 - 42)
Method for Calculating Viscosity Index (D 567 - 41)

Accepted for Publication as Information Only:

Test for Micro Cone Penetration of Lubricating Greases
Test for Apparent Viscosity of Lubricating Greases
Definitions, Functions, Types, and Designations of Cutting Fluids
Proposed Carburetor Jacket for Use with Motor and Research Methods to Rate High Vapor Pressure Fuels
Determination of Color Index of Petroleum Products by Photoelectric Colorimeter
Test for Sulfur in Petroleum Products by the CO_2 - O_2 Lamp Method with Supplement

Committee D-16 on Industrial Aromatic Hydrocarbons:

Report presented from manuscript, in the absence of the chairman, by P. J. Smith and accepted as a report of progress.

Committee D-15 on Engine Antifreezes:

Report presented, in the absence of the chairman, by P. J. Smith and accepted as a report of progress.

Committee D-11 on Rubber and Rubber-Like Materials:

Report presented by Simon Collier, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Thermoplastic Vinyl Polymer Sheath Compound for Electrical Insulated Cords and Cables
Spec. for Rubber Insulating Line Hose (Proof Test, 20,000 volts, 3 Minutes)
Spec. for Rubber Insulating Hoods (Proof Test, 20,000 volts, 3 Minutes)
Spec. for Rubber Insulating Sleeves (Proof Test, 10,000 volts, 3 Minutes) with the following further revisions:

Fig. 1.—Change "small and medium" to read "regular and long."

Section 3.—Omit the phrase "for full-length sleeves and 10 ma. for elbow length sleeves" and add the following footnote: "[3] There is reason to believe that present-day sleeves conforming to these specifications would readily withstand a higher proof-voltage test than 10,000 v. if a testing procedure could be devised for testing the sleeves with water electrodes but without folding the sleeve. One procedure which has given some promise of success in this direction uses a snugly-fitting porcelain plug 2½ in. in thickness inserted at the cuff end of the sleeve after coating with a silicone grease (Dow-Corning DC-4 compound is one which has been found satisfactory); the cuff is then bound tightly over the plug with rubber cable bandage. The plugged sleeve is now filled with water to within 2½ in. of the top edge and immersed in water to the same level."

Section 7.—Change to read as follows: "Unless otherwise specified each sleeve shall be marked only with the style letter (R, L, or B), the manufacturer's name, the catalogue number, the A.S.T.M. Designation D——, and the ASA Designation J6.5. Such marking shall be confined to the shoulder flap and shall be done so as not to injure the sleeve. The style letter shall be molded into the outer rubber surface of the shoulder flap. If ink is used for the other required markings it shall be indelible and nonconducting."

Section 16 (a).—Change to read as follows:

(*a*) *Test Specimens.*—Specimens cut from selected samples and tested in accordance with Paragraph (*b*) shall conform to the requirements for physical properties prescribed in Section 4 (*a*), (*b*), (*c*), and (*e*). In addition, two specimens cut so that the seam passes through the approximate center of the reduced section at right angles to the length of the specimen, when tested in accordance with Paragraph (*b*), shall conform to the requirements of Section 4 (*d*).

Spec. for Rubber Insulating Blankets (Without Fabric Reinforcement) (Proof Test, 16,000 volts, 3 Minutes) with the same revision as given above for Section 7 of the Specifications for Sleeves

Spec. and Methods of Test for Latex Foam Rubbers

Spec. and Methods of Test for Sponge and Expanded Cellular Rubber Products

Test for Resistance of Vulcanized Rubber or Synthetic Elastomers to Cut Growth by the Use of the Ross Flexing Machine

Method of Measuring Low-Temperature Stiffening of Rubber and Rubber-Like Materials by the Gehman Torsional Apparatus

Test for Impact Resilience and Penetration of Rubber by the Rebound Pendulum

Accepted as Tentative, Revisions in:

Methods of Testing Rubber Hose (D 380 - 46 T)

Test for Compression Set of Vulcanized Rubber (D 395 - 47 T)

Methods of Testing Rubber Insulated Wire and Cable (D 470 - 48 T) except that the new Section 8 on Oil Immersion Test will provide for the use of A.S.T.M. Oil No. 2 as described in Table I of Methods D 471 instead of the oil specified in Section 8 (*c*) of Specifications D 752.

Spec. for GR-M Polychloroprene Sheath Compound for Electrical Insulated Cords and Cables (D 752 - 46 T)

Test for Mechanical Properties of Elastomeric Vulcanizates under Compressive or Shear Strains by the Mechanical Oscillograph (D 945 - 48 T)

Methods of Dynamic Testing for Ply Separation and Cracking of Rubber Products (D 430 - 40)

Adopted as Standard:

Spec. for Rubber Sheath Compound for Electrical Insulated Cords and Cables (D 532 - 46 T), as revised

Adopted as Standard, Revisions in:

Test for Indentation of Rubber by Means of the Pusey and Jones Plastometer (D 531 - 41)

Spec. for Cotton Rubber-Lined Fire Hose for Public and Private Fire Department Use (D 296 - 38)

Method of Testing Compressed Asbestos Sheet Packing (D 733 - 46)

Spec. for GR-M Polychloroprene Sheath Compound for Electrical Insulated Cords and Cables Where Extreme Abrasion Resistance is not Required (D 753 - 47)

Withdrawal of Tentative Method:

Test for Low-Temperature Brittleness of Rubber and Rubber-Like Materials (D 736 - 46 T)

Editorial Changes Accepted in:

Test for Changes in Properties of Rubber and Rubber-Like Materials in Liquids (D 471 - 46 T)

Accepted for Publication as Information Only:

Spec. and Methods of Test for Concentrated, Ammonia Preserved, Creamed and Centrifuged Natural Rubber Latex

Committee D-6 on Paper and Paper Products:

Report presented by W. R. Willetts, chairman, and the following actions taken:

Accepted as Tentative:

Method for Creasing Paper for Permeability Tests

Test for Fiber Analysis of Paper and Paperboard

Test for Ply Separation of Combined Container Board

Test for Scuff Resistance of Paperboard

Adopted as Standard:

Test for Bleeding Resistance of Asphalted Paper at Elevated Temperature (D 917 - 47 T)

Test for Blocking Resistance of Paper and Paperboard (D 918 - 47 T)

Test for Copper Number of Paper and Paperboard (D 919 - 47 T)

Test for Crease Retention of Wrapping Paper (D 920 - 47 T)
Test for Titanium Dioxide in Paper (D 921 - 47 T)

Adopted as Standard, Revisions in:

Method of Conditioning Paperboard, Fiberboard and Paperboard Containers for Testing (D 641 - 43)

Reaffirmation of Standards:

Test for Bulking Thickness of Paper (D 527 - 41)
Test for Machine Direction of Paper (D 528 - 41)
Test for Water-Soluble Acidity or Alkalinity of Paper (D 548 - 41)
Method of Sampling Paper and Paper Products (D 585 - 42)
Test for Ash Content of Paper and Paper Products (D 586 - 42)
Test for Casein in Paper (D 587 - 42)
Test for Alpha-, Beta-, and Gamma-Cellulose in Paper (D 588 - 42)
Test for Paraffin Content of Waxed Paper (D 590 - 42)
Test for Starch in Paper (D 591 - 42)
Test for Folding Endurance of Paper (D 643 - 43)
Test for Thickness of Paper and Paper Products (D 645 - 43)

Committee D-10 on Shipping Containers:

Report presented from manuscript, in the absence of the chairman, by P. J. Smith and accepted as a report of progress.

TWENTY-SECOND SESSION—CEMENTITIOUS AND BUILDING MATERIALS

FRIDAY, JULY 1, 2 P.M.

SESSION CHAIRMAN: F. H. JACKSON

Committee C-8 on Refractories:

Report presented by R. B. Sosman, chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Chemical Analysis of Refractory Materials (C 18 - 45)
Spec. for Refractories for Heavy Duty Stationary Boiler Service (C 64 - 48)
Spec. for Refractories for Incinerators (C 106 - 48)
Spec. for Refractories for Moderate Duty Stationary Boiler Service (C 153 - 48)

Adopted as Standard, Revisions in:

Method for Basic Procedure in Panel Spalling Test for Refractory Brick (C 38 - 47)
Method of Testing Refractory Brick Under Load at High Temperatures (C 16 - 41)
Def. of Terms Relating to Refractories (C 71 - 47)
Test for Cold Crushing Strength and Modulus of Rupture of Refractory Brick and Shapes (C 133 - 39)
Method of Panel Spalling Test for Fireclay Plastic Refractories (C 180 - 47)

Reaffirmation of Standards:

Classification of Fireclay Refractories (C 27 - 41)
Test for Size and Bulk Density of Refractory Brick (C 134 - 41)
Test for Warpage of Refractory Brick and Tile (C 154 - 41)

Committee C-17 on Asbestos-Cement Products:

Report presented from manuscript by H. R. Snoke, chairman, and accepted as a report of progress.

Committee C-1 on Cement:

Report presented by F. H. Jackson, chairman, and the following actions taken:

Accepted as Tentative:

Test for Sodium Oxide and Potassium Oxide in Portland Cement by Flame Photometry
Test for Setting Time of Hydraulic Cement
Spec. for Flow Table for Use in Tests of Hydraulic Cements

Accepted as Tentative, Revisions in:

Spec. for Natural Cement (C 10 - 37)
Spec. for Portland Cement (C 150 - 47)
Test for Air Content of Air-Entraining Portland Cement Mortar (C 185 - 47 T)[11]

Adopted as Standard, Revisions in:

Spec. for Portland Cement (C 150 - 47)
Test for Autoclave Expansion of Portland Cement (C 151 - 43)[11]

Spec. for Masonry Cement (C 91 - 48)[11]
Test for Compressive Strength of Hydraulic-Cement Mortars (C 109 - 47)[11]
Test for Heat of Hydration of Portland Cement (C 186 - 47)[11]
Test for Normal Consistency of Hydraulic Cement (C 187 - 44)[11]
Test for Soundness of Hydraulic Cement Over Boiling Water (Pat Test) (C 189 - 44)[11]
Test for Tensile Strength of Hydraulic-Cement Mortars (C 190 - 44)[11]
Test for Time of Setting of Hydraulic Cement by the Vicat or Gillmore Needles (C 191 - 44)[11]

Editorial Changes Accepted in:

Test for Fineness of Portland Cement by the Turbidimeter (C 115 - 42)
Test for Fineness of Portland Cement (C 204 - 46 T)
Chemical Analysis of Portland Cement (C 144 - 48 T)

Committee C-15 on Manufactured Masonry Units:

Report presented, in the absence of the chairman, by L. C. Gilbert and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Building Brick (Made from Clay or Shale) (C 62 - 44)
Spec. for Sewer Brick (Made from Clay or Shale) (C 32 - 42)
Spec. for Structural Clay Load-Bearing Wall Tile (C 34 - 41)
Spec. for Structural Clay Non-Load-Bearing Tile (C 56 - 41)
Spec. for Structural Clay Floor Tile (C 57 - 39)
Def. of Terms Relating to Structural Clay Tile (C 43 -49)
Methods of Sampling and Testing Brick (C 67 - 44) with a correction in the last sentence of Section 39 (*b*), as preprinted, in which "0.02 in." is changed to read "32nds of an inch."

Adopted as Standard:

Def. of Terms Relating to Structural Clay Tile (C 43 - 46 T)

Adopted as Standard, Revisions in:

Spec. for Building Brick (Made from Clay or Shale) (C 62 - 44)
Spec. for Structural Clay Load-Bearing Wall Tile (C 34 - 41)
Spec. for Structural Clay Non-Load-Bearing Tile (C 56 - 41)
Spec. for Structural Clay Floor Tile (C 57 - 39)

Editorial Change Accepted in:

Spec. for Structural Clay Facing Tile (C 212 - 48 T)

Papers:

Size and Border Conditions of Test Specimen in Their Relation to Results of Fire Tests—S. H. Ingberg, presented by the author.
Long-Time Tests of Concrete Containing Cements of Types I, II, and III Under Various Storage Conditions—W. J. McCoy and S. B. Helms, presented from manuscript by Mr. McCoy.
The Use of Natural Anhydrite in Portland Cement—W. C. Hansen and J. O. Hunt, presented by Mr. Hansen.[12]
The Direct and Continuous Measurement of Bleeding in Portland Cement-Water Mixtures —Rudolph C. Valore, Jr., James E. Bowling, and R. L. Blaine, presented by Mr. Valore.

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[11] The revisions in these standards comprise the changes in glass graduates and in standard laboratory conditions as covered in the report of Committee C-1.

[12] Published in ASTM BULLETIN, No. 161, October, 1949 p. 50.

THE PROGRESS OF A.S.T.M.

ANNUAL ADDRESS OF THE PRESIDENT

R. L. TEMPLIN[1]

JUNE 28, 1949

I AM sure that members of the American Society for Testing Materials are interested in the progress of the Society. Those interested in the historical progress of the organization will find it has been ably presented on a number of occasions by former presidents. A particularly noteworthy review covering the first half-century of the organization was given by President A. W. Carpenter in 1947.

A complete and factual review of the progress made recently can be obtained from a perusal of the Annual Report of the Board of Directors and, in fairness to those you have selected to administer the affairs of the Society and as evidence of your interest as members, it merits your serious consideration.

The satisfactory future progress of our Society, in accordance with its basic purposes, requires that the activities of the Society be kept closely attuned to the needs of those whom it serves. These include industry, other technical societies, the U. S. Government, technologists, and many others. With the primary objectives of promoting the knowledge of and the standardizing of materials and test methods, many opportunities are presented for expanding the scope of the activities of the Society. The need for more standards and test methods suitable for the development and application of new materials is very much in evidence. While this has been recognized by others, the fact still deserves emphasis by repetition.

For satisfactory progress it is necessary frequently to review specifications and test methods which were suitable for the purposes of yesterday but which may be inadequate for those of today and tomorrow. In past years, for example, emphasis has been placed upon test methods which were intended to be a part of material or product specifications. In many instances the methods have been defined only in sufficient detail suitable for routine inspection tests. When these tests are used for more precise investigation of the materials the deficiencies in the test method details often become manifest. Specifically, the standard round, $\frac{1}{2}$-in. diameter, tension test specimen for metals as specified by A.S.T.M. has proved to be quite satisfactory for routine inspection in so far as tensile strength, yield point or yield strength, elongation and reduction in area are concerned, but it is not suitable for precise determination of the tensile modulus of elasticity.

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[1] Assistant Director of Research and Chief Engineer of Tests, Aluminum Company of America, New Kensington, Pa.

The use of dissimilar rectangular cross-section tension specimens for certain metal products makes comparisons of elongation values difficult or erroneous when different permissible sizes of specimens are involved.

The cold bend test is called for in a number of our metal product specifications, yet we do not have a standard detailed method for making this test. Under such conditions the bend requirements lose much of their significance.

The shearing properties of materials are often of interest to designers of engineering structures, but A.S.T.M. has no standard methods for making shearing tests of metals. Again, the fatigue properties of metals are very important to designers of machines and structures subjected to repeated loads, but so far no standard fatigue testing procedures for metals have been adopted by our Society.

Although we have standards for verification of testing machines and load measuring devices for checking testing machines, yet currently we have no standards for strain or deformation measuring apparatus.

These examples are some with which I am familiar but there are undoubtedly numerous others in the same category in the many fields of interest to our Society.

Many tests not directly a part of product specifications are often used for the improvement of commercial products and the development of new products. Currently too few of the users of these tests appreciate the merits of suitably standardized test methods for the purposes just indicated. In most tests, factors exist which, if not properly controlled, will cause substantial variations in test data. These differences in results may be erroneously attributed to the variables being studied, whereas in reality they are caused by uncontrolled variations in testing procedure. Departures from the standard sizes and geometry of tension test specimens in investigational studies of metals are often in evidence. Much attention, therefore, must be given to all the details involved when carrying out investigational testing, in order to attain precision.

Presumably many of the new products now being developed will require standards and undoubtedly some of these materials will require new tests. Certainly new uses of both old and new products often indicate the need for new tests. The technical symposia sponsored by A.S.T.M. have proved to be an effective means for developing these needs.

To deal adequately with the problems that have been only briefly indicated, much additional experimental or research work will be required. A considerable amount of such work is currently in progress as shown by the papers presented at this Annual Meeting, but more work will be necessary before suitable standards can be adopted. Effort of this character serves to emphasize the interest of our Society in research.

The increasing number and variety of new materials and their practical applications have increased the opportunities of A.S.T.M. and broadened the horizons of its interests. If we take proper advantage of the possibilities thus afforded, there need be no concern about the future progress of our Society.

ANNUAL REPORT OF THE BOARD OF DIRECTORS*

This report of the Board of Directors to the Society is presented to the members at an annual meeting that marks the conclusion of a most active year—one that represents much in accomplishment of our technical committees, as may be seen by examination of the current committee reports. The year also has seen our work expand into important new fields, which in turn has brought into the Society new members to work out their testing and specification problems in the environment and under the established procedures of A.S.T.M. This kind of growth, which has of course been going on for years, is the soundest possible foundation upon which to build the future accomplishments of the Society. The Board cordially welcomes all the new members who have affiliated with us during the year and also wishes to commend our committees and their members for the splendid work they are doing to advance research and standardization in the materials field. Also to those who present to the Society the results of their researches in the form of technical papers and discussions, the Board extends a sincere word of appreciation, for it is the combination of committee work and technical papers that enables the Society to accomplish the purposes for which it exists—"the promotion of knowledge of the materials of engineering, and the standardization of specifications and the methods of testing."

The report records briefly the principal happenings and developments of the Society year, including matters of policy and administration. New publication policies announced a year ago are being put into effect. On the financial side, the Society's position has been materially strengthened by the increase in dues that has been so splendidly supported by individual and company members alike. We are still on the inflationary spiral with respect to costs of goods and services, especially printing, which has greatly increased our operating expenses and leaves less than is needed for support of expanded activities and increased services to members. Happily, there are signs that costs may be at their peak and that the situation may take a more favorable turn. This important phase of Society operations is covered fully in the section of this report on finances, and merits the attention of each member.

At best this report, together with the reports of the Administrative Committees appended, is but an outline of progress during the year; it must be filled in with the wealth of technical data, tests and specifications presented to the members at this annual meeting and in the many publications issued and others being planned. The importance, too, of the meetings held in the several districts of the Society cannot be exaggerated, for such meetings carry to members and others throughout the country the real meaning of the Society and its work. Finally, the significance of our first national meeting west of the Rockies, to be held next October in San Francisco, is far reaching, for it marks the first time the work of A.S.T.M. has been displayed so intimately to our members in the rapidly growing industries in the Pacific Area. A splendid technical program has been arranged, together with a number of important committee meetings, and the Board earnestly hopes that as many members as possible will attend this meeting and help make it an outstanding success.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

Technical Activities

The technical work of the Society has been actively carried on during the year, as will be seen in the committee reports for this meeting, and the number of new specifications and methods submitted for action. The Administrative Committee on Standards is responsible for following the standardization activities of the Society and in its annual report to the Board (Appendix II) records a number of interesting developments. The committee fulfills an important function in passing upon new and revised tentatives between annual meetings of the Society, thereby speeding up the Society's procedure and at the same time insuring critical consideration of committee recommendations, and the record of that work during the past year is most impressive. The committee is also conducting valuable studies of proposals for extension of the Society's activities into new fields, among which are asphalt floor tile and other hard surface floor coverings, floor waxes, wall tile, and graphite. The Administrative Committee continues to give particular attention to improving the quality of A.S.T.M. standards from both editorial and technical points of view.

The Administrative Committee on Research, whose annual report to the Board appears as Appendix III, has submitted to the technical committees a suggested type of committee organization for handling research activities, based upon conferences with the officers of some ten committees representing various degrees of interest and participation in research and a questionnaire to all committee officers. Many committees are already soundly organized for carrying out research projects related to their needs for data on materials and methods of test, and others are giving thought to the matter. Considerable progress has also been made in preparing statements of unsolved problems in the respective committee fields, for possible publication as an initial listing of research projects for the use of schools, research foundations, and industry. Further work will be done along these lines during the coming year.

Two other administrative committees deal with certain phases of our technical activities, namely, the Administrative Committee on Ultimate Consumer Goods and the Administrative Committee on Simulated Service Testing. The annual reports of these two committees appear as Appendices V and VI, respectively, and record briefly the progress made in these respective fields of work. These reports speak for themselves. However, the Board would point out that in the field of consumer goods, the Administrative Committee has worked out a procedure in the technical committees for development of standards for such goods, involving a modification of the Regulations Governing Technical Committees that is covered in a later section of this report. An advisory group of social and natural scientists has been formed whose functions are described in the appended report.

New Activities:

A new technical Committee E-12 on Appearance was organized in September, 1948. The considerations leading to the organization of this committee were presented in the Board's report a year ago, together with a statement of purpose and proposed activities, which with a minor editorial revision has been approved as the official statement of scope. In brief, the purpose of this committee is "to improve and develop methods for describing and evaluating the appearance properties (such as color, gloss, opacity, and texture) of engineering materials." At the organization meeting M. Rea Paul was elected chairman, R. C. Adams, vice-chairman, and Daniel Smith, secretary.

A second committee was organized in October, 1948, Committee C-21 on Ceramic Whitewares, which as explained in the Board's report a year ago has come about through the request of the American Ceramic Society that A.S.T.M. take over the development of test methods and specifications in this field. A formal statement of scope of the committee is still under consideration. The following officers were elected: J. H. Koenig, chairman, J. R. Beam, vice-chairman, and R. F. Geller, secretary.

Still a third new committee was formed during the year, C-20 on Acoustical Materials, on May 3, 1949. The organization of this committee stemmed from a recommendation of the Administrative Committee on Standards, to which detailed reference was made a year ago. H. A. Leedy was elected chairman, C. M. Harris, vice-chairman, and H. J. Sabine, secretary. A formal statement of scope is under consideration.

In the Board's report a year ago it was mentioned that the Administrative Committee on Standards was studying the desirability of establishing an A.S.T.M. committee in the field of porcelain enamel. During the year this study led to a specific proposal, pursuant to which the Board has authorized the formation of an A.S.T.M. Committee on Porcelain Enamel, to which the designation C-22 will be assigned. W. N. Harrison has been appointed chairman pro-tem with the responsibility of recommending personnel and scope of the committee and arranging for its formal organization.

Work has been started on test methods and terminology for printing inks. A conference of manufacturers and users of printing inks was held at Society Headquarters on May 18, 1949, at which it was decided to organize a committee on the subject. Because the raw materials and test methods employed in printing inks are quite similar to those applying to paints and lacquers, this committee is being set up for the moment under the aegis of Committee D-1 on Paint, Varnish, Lacquer, and Related Products. The first meeting of this committee will be held during the annual meeting.

The decision of Committee E-2 to confine its scope to emission spectrography and not to cover the absorption spectrographic technique, in which decision the Board of Directors has concurred, has led the Board to authorize the formation of a separate technical committee on absorption spectrography. Considerable work in this field has already been done in some committees of the Society, notably in the petroleum and allied fields, and it is planned to hold soon a conference of members and committee representatives interested in the subject preliminary to the formal organization of the new committee.

During the year the Board has considered a number of suggestions for new fields of work developed and reported to it by a special committee charged with this responsibility. Certain of these suggestions fall within the scope of existing committees and will be discussed with those committees during the coming year. One such subject, namely, ultrasonic methods of test, has already been taken up by Committee E-7. Other suggestions, if found practicable and commanding the necessary support of interested parties, will involve the organization of new committees. One such subject is that of absorption spectrography referred to above.

A.S.T.M. Corrosion Test Sites:

Our work in the field of corrosion testing is perhaps one of the most important activities in the Society. It has been carried on for upwards of forty years by individual committees interested in specific materials and has made many major contributions to engineering knowledge in this field. At the moment seven committees of the Society are engaged in this type of work. The cooperative nature of the work, with the participation therein of both producer and consumer interests as well as the careful planning and critical evaluation of results, has led to a wide acceptance of the published data as engineering facts that can be relied upon in design.

At first, the coordination of this work was solely through interlocking membership and cooperation between committees working in fields of mutual interest. In 1942, coordination of corrosion testing in the Society was placed in the hands of the Advisory Committee on Corrosion, on which serve representatives of committees interested in corrosion testing, and to this committee has also been assigned responsibility for the acquisition and maintenance of test sites for use by committees of the Society. At present some twenty-five exposure sites are being used, for most of which we have no clearly defined security of tenure. Some test programs have been interrupted because we have had to give up donated test sites or to move test sites to new locations. Efficient servicing of so many scattered sites has been a problem.

During the past year the Advisory Committee on Corrosion has developed plans to procure, for definite rights of occupancy for suitable periods of time, a smaller number of sites (probably not over ten) that experience has shown can be chosen to insure maximum coverage of service conditions not only for corrosion testing of metals but also exposure tests of a variety of materials, such as paints, plastics, textiles, and ceramics. To support this program the committee plans to raise $100,000 of expendable funds to meet the needs of approximately ten years. In a formal report to the Board of Directors the committee outlined these plans and requested the Board to advance monies from the General Funds of the Society to initiate the work, and to add to the headquarters staff an engineer to service the sites and specimens and in general to advance the whole test site program, it being felt that such a staff man working under the general direction of the Advisory Committee on Corrosion is necessary for efficient operation of this extensive program. The costs of the work, including salary of the staff man, are to be met from the funds to be raised.

The Board of Directors, confident that this work has demonstrated to industry the importance of carrying it on in the future in the most effective manner possible, has approved the Advisory Committee's recommendations. It has agreed to advance to the Advisory Committee up to $10,000 to meet initial costs, and it has added to the staff a young engineer to engage in this work. It is understood that monies advanced from the General Funds for this purpose will be repaid from the funds that the Advisory Committee is now raising.

A brochure has been prepared which describes current and proposed corrosion projects, the types and probable locations of the test sites being acquired, and the needs for further work. A copy of this brochure may be obtained by any member of the Society who is interested.

It is understood, of course, that these A.S.T.M. test sites when acquired will be available to any committees of the Society that desire to conduct exposure tests.

The Board earnestly commends this

entire program to all interested A.S.T.M. committees and asks for the wholehearted support of all industries that are in any way concerned with determining the resistance of materials to deterioration.

Committee Scopes and Appointments:

Scopes of several of the committees of the Society have been passed upon by the Board and the approved scopes are given here as a matter of official record.

Committee C-4 on Clay Pipe (revised by addition of italicized words):

> The formulation of specifications, nomenclature and methods of test for clay pipe used for the conveyance of sewage, industrial wastes and storm waters, *and for clay flue linings.*

Committee C-15 on Manufactured Masonry Units (revised by addition of italicized words):

> The formulation of specifications, methods of test and definitions relating to units of inorganic substances such as building brick of clay, sand-lime and concrete; structural clay tiles; paving brick, hollow concrete units; sewer brick and block; glazed building units; *chemical resistant units; and drain tile.* The units shall not include natural building stone or slate nor products for use as refractories.

Committee C-19 on Structural Sandwich Constructions (new):

> The formulation of test methods and specifications applicable to structural sandwich constructions. Test methods and specifications on basic materials, as covered by other committees, shall be used when applicable.

Committee D-9 on Electrical Insulating Materials (revised):

> Development of methods of sampling and testing, and formulation of specifications for electrical insulating materials, including research concerning the properties of such materials and products.

Committee E-1 on Methods of Testing (revised):

> (*a*) To aid and advise the technical committees of the Society in the preparation of standard methods and development of instruments of testing, in the correlation of similar methods prepared by different committees, and in instituting cooperation between the technical committees on matters of common interest relating to methods and instruments of testing, by the creation of subcommittees of Committee E-1 or otherwise.
>
> (*b*) To initiate, conduct, and report work upon the determination of properties of materials, and to prepare methods of testing and specifications for instruments for testing materials of interest to the Society not coming within the scope of any other technical committee.
>
> (*c*) To encourage, secure and promote, with the approval of the Board of Directors, cooperation between technical committees of this Society and the committees of other societies and associations as regards methods and instruments of testing.
>
> (*d*) To standardize the nomenclature and definitions used in or relating to testing methods or instruments in cooperation with Committee E-8 on Nomenclature and Definitions.
>
> (*e*) To perform such other functions as may advance, improve, standardize and unify the procedures of materials testing.

Committee E-7 on Non-Destructive Testing (revised):

> Promotion of knowledge and advancement of the art of non-destructive testing of engineering materials for discontinuities or structural irregularities, and extensions of the methods used to other engineering problems; the formulation of requirements relating to the performance, interpretation and classification of results of such tests, without prejudice to the jurisdiction of product committees over their respective products; and the coordination and review of non-destructive testing clauses initiated by other committees.

Joint Committee on Effect of Temperature on the Properties of Metals (revised):

> To sponsor investigations leading to the accumulation, evaluation, and dissemination of data on the engineering properties of metals at high and low temperatures and the standardization of test methods pertaining thereto.

In acting upon the revised scope of Committee D-9, the Board took cognizance of inevitable overlapping in scopes of Committees D-9, D-11 on Rubber and Rubber-Like Materials, D-13 on Textile Materials, and D-20 on Plastics. Jurisdictional questions raised in the work of these committees are being pointed out to the officers with the suggestion that new problems undertaken by any of them be analyzed carefully with respect to possible relationship to the activities of the other committees.

In approving the revised statement of scope of Committee E-1 on Methods of Testing, the Board also reviewed the revised regulations governing the activities of that committee designed to give effect to decisions of the Board set forth in its 1947 report. The Board feels that these revised regulations give every promise of accomplishing the objectives sought in the reorganization of Committee E-1, although it must be recognized that success of the committee depends greatly upon sincere cooperation between E-1 and the other committees of the Society.

Growing interest in the work of the Joint Committee on Chemical Analysis by X-ray Diffraction has led to the appointment on the committee of representatives of a number of A.S.T.M. technical committees.

District Activities

As indicated in the Report of the Administrative Committee on District Activities which is appended (Appendix VII), no major administrative matters have come up during the past year. The districts functioned well under the A.S.T.M. District Charter and Manual, and as indicated in the accompanying table numerous successful and interesting meetings were sponsored. The final organization of the Ohio Valley District is still to be completed.

Mention should be made of certain district activities in connection with functions of the Society. The Chicago District acted as host during the 1949 Spring Meeting in March and arranged an interesting dinner and program of entertainment. The two districts in California, Northern and Southern, have been a nucleus for the General Committee on Arrangements for the first Pacific Area National Meeting. The Philadelphia District will act as official host during the 1949 Annual Meeting in Atlantic City and is sponsoring the annual dinner and entertainment and also the ladies' entertainment program.

District Meetings:

One significant practice which has much to commend it has been particularly prevalent during the year and that is the sponsoring of local meetings jointly with the sections and chapters of other national organizations. The accompanying table indicates where meetings were of a joint nature.

Several of the district-sponsored meetings were outstanding, including the one in Philadelphia on February 10, 1949, the technical program of which comprised a Symposium on Industrial Quality Control. There were over 400 in attendance at dinner and at the afternoon and evening sessions, in spite of the fact that on that day Philadelphia had one of its heavy snowstorms of the winter. Another meeting with a large attendance was that in New York last October, which involved domestic house-heating, with three speakers and an attendance of 450.

President Templin spoke at eleven of the district meetings, in the eastern districts giving his paper on "Aluminum," and in California—Los Angeles and San Francisco—speaking on "Mechanical Properties of Metals." His paper on "Aluminum" and others presented at district meetings, as noted in the table, have been published in the ASTM BULLETIN.

National Meetings

To provide ample facilities for the large number of sessions and committee meetings and the Eighth Exhibit of Testing Apparatus and Related Equipment at the 1948 Annual Meeting in Detroit, it was necessary to schedule the events at three different hotels. By careful scheduling of the committee meetings so that they dovetailed well with the sessions, there was a minimum of confusion. While it is desirable to have all of the annual meeting events in one hotel if possible, the Detroit experience indicates that the meetings can be split if necessary. The Detroit District Council acting as a committee on arrangements sponsored the annual dinner and arranged an outstanding entertainment program for the ladies.

The 1949 Spring Meeting featured a Symposium on Aging of Rubbers held during Committee Week in Chicago. There were upwards of 1100 registered throughout the week, with approximately 300 committee meetings scheduled over five days.

With the continuing extension of the Society's work into new fields and the larger number of technical committees, the problem of arranging 300 to 400 meetings of technical committees during a week's period is becoming somewhat acute. Conflicts due to overlapping committee memberships are avoided in so far as possible, but it is not possible to avoid all of these. The problem is further complicated at annual meetings where it is necessary also to coordinate committee meetings with the technical sessions of the Society. Committee work is so vital to progress of the Society that every effort is made to schedule such meetings as efficiently as possible.

Pacific Area National Meeting:

The first national meeting of the Society in the Pacific Area at San Francisco the week of October 10, 1949, should be an outstanding one. The Board of Directors has appointed a General Committee on Arrangements, as announced in the March, 1949, issue of the BULLETIN, which has effectively organized for the various features of the meeting, notably the technical program of 70 papers by outstanding authorities in a variety of materials and testing fields, and the entertainment and social events planned for the week. An important feature is the fact that ten technical committees and many of their subcommittees will meet throughout the week, making this a truly national meeting of the Society.

A complete announcement of the meeting is being mailed to each member and committee member this month, with further details to appear in the July and September BULLETINS.

1950 Meetings:

The 1950 Annual Meeting, the Society's Fifty-Third, will be held at Chalfonte-Haddon Hall, Atlantic City, through the week of June 26, with the Ninth Exhibit of Testing Apparatus and Related Equipment in progress concurrently.

The 1950 Committee Week and Spring Meeting will be held at the Hotel William Penn in Pittsburgh during the week of February 27.

A.S.T.M. MEETINGS JUNE, 1948–MAY, 1949, INCLUSIVE.

Meeting	Place and Date	Notes
Annual Meeting	Detroit, Mich. Hotels Book-Cadillac, Statler, Detroit-Leland June 21–25, 1948	19 Technical Sessions 400 Committee Meetings, 8th Testing Apparatus Exhibit & Photographic Exhibit (Registered Attendance—1768)
A.S.T.M. Committee Week	Chicago, Ill. Edgewater Beach Hotel February 28–March 4, 1949	300 Committee Meetings (Over 1100 in attendance)
Spring Meeting	Chicago, Ill. Edgewater Beach Hotel March 2, 1949	Symposium on Aging of Rubbers (About 400 in attendance) District Dinner and Entertainment
District or Local (sponsored by Councils indicated)	Philadelphia, Pa. Franklin Institute October 13, 1948	Good Design—On Purpose! by W. T. Bean, Jr. (150 in attendance)
	Washington, D. C. Wardman Park Hotel October 14, 1948	Aluminum,[a] by R. L. Templin; The Five Outstanding Developments in Textiles During the Last Decade,[b] by F. Bonnet. (125 in attendance)
	Chicago, Ill. W.S.E. Headquarters October 19, 1948	Jointly with Western Society of Engineers Aluminum,[a] by R. L. Templin; Remarks, by V. O. McClurg (85 in attendance)
	New York, New York Engineering Societies Bldg. October 26, 1948	Jointly with N. Y. Section A.S.M.E. and A.S.H.V.E. Latest Developments in Domestic House-Heating: Electric Panel Heating, by H. H. Weber; Hot Water Panel Heating, by Peter B. Gordon; Heat Pump, by W. L. Knaus. (450 in attendance)
	St. Louis, Mo. Engineers Club November 4, 1948	Jointly with St. Louis Chapter A.S.M. Recent Milestones in Metals and Minerals,[c] by John D. Sullivan, presented by Bruce W. Gonser. (165 in attendance)
	Philadelphia, Pa. Franklin Institute November 10, 1948	Aluminum,[a] by R. L. Templin (135 in attendance)
	Cleveland, Ohio Cleveland Engineering Society November 16, 1948	Aluminum,[a] by R. L. Templin (about 100 in attendance)
	Worcester, Mass. (New England) Sheraton Hotel November 19, 1948	Jointly with New England Section TAPPI Specifications and Quality Control: The Philosophy o Specifications,[d] by Wm. R. Willets and L. S. Reid: Practical Quality Control, by G. P. Wadsworth. (about 150 in attendance)
	Pittsburgh, Pa. Mellon Institute Auditorium November 29, 1948	Weather and Man, by Hans H. Neuberger. (75 in attendance)
	Los Angeles, Calif. (Southern California) Rodger Young Auditorium November 30, 1948	Smog Testing, by L. C. McCabe (110 in attendance)
	New York, N. Y. Engineering Societies Bldg. December 7, 1948	Television Demonstration and Lecture: Standardizations i the Television Industry, by R. D. Kell. (about 200 in attendance)
	New York, N. Y. Engineering Societies Bldg. February 3, 1949	Jointly with N. Y. Section ASME, Machine Design Div. Aluminum and Its Uses, Including Application in Machine Design,[a] by R. L. Templin; Film—From Mine to Metal. (150 in attendance)
	Philadelphia, Pa. McCallister's February 10, 1949	Jointly with Phila. and Wilmington Sections A.S.Q.C. Symposium on Industrial Quality Control (afternoon) Organizing for Quality and Waste Control, by E. H MacNiece; Study of Process Capabilities and Applicatio at the Foreman's Level, by Anthony Oladko; dinner address—Management Looks at Quality Control, by Genera D. Armstrong; (evening) Mobilizing for Quality Contro by Jos. N. Juran; Lecture and Training Film on Qualit Control, by Simon Collier. (425 in attendance)
	Detroit, Mich. Rackham Memorial Bldg. February 21, 1949	Aluminum,[a] by R. L. Templin; Austin Grant (Radio Commentator) (285 in attendance)

A.S.T.M. MEETINGS JUNE, 1948–MAY, 1949, INCLUSIVE (*Continued*).

Meeting	Place and Date	Notes
District or Local (sponsored by Councils indicated)	Rochester, N. Y. (Western New York-Ontario) Rochester Engineering Society March 10, 1949	Major Sources of Energy, by Eugene Ayres. (75 in attendance)
	Los Angeles, Calif. (Southern California) Rodger Young Auditorium March 15, 1949	Determination and Significance of Mechanical Properties of Metals, by R. L. Templin; Trends in Materials Testing and Research, by C. L. Warwick. (85 in attendance)
	Chicago, Ill. Stevens Hotel March 15, 1949	Jointly with Chicago Section A.I.M.E. Panel on Critical Materials. Two Speakers, Jos. K. Stone, Jr. and R. L. Wilcox; as Part of Chicago Production Conference.
	Philadelphia, Pa. Franklin Institute March 22, 1949	Industrial Stream Pollution: The Problem, by Norris W. Vaux;[e] The Cure, by W. B. Hart. (300 in attendance)
	San Francisco, Calif. (Northern California) Engineers Club March 25, 1949	Determination and Significance of Mechanical Properties of Metals, by R. L. Templin; Trends in Materials Testing and Research, by C. L. Warwick. (75 in attendance)
	New York, N. Y. Engineering Societies Bldg. April 5, 1949	Major Sources of Energy, by Eugene Ayres. (65 in attendance)
	Cambridge, Mass (New England) Mass. Institute of Technology April 14, 1949	Light Metals and Alloys: Aluminum,[a] by R. L. Templin; Titanium, by Bruce W. Gonser; Magnesium Alloys and Applications,[f] by John C. McDonald. (150 in attendance)
	Pittsburgh, Pa. University Club May 4, 1949	Smoker: Remarks by R. L. Templin and C. L. Warwick. (50 in attendance)
	St. Louis, Mo. York Hotel May 11, 1949	Opacity and Its Development in Porcelain Enamels, by Andrew I. Andrews.

[a] Published in ASTM BULLETIN No. 158, May, 1949, p. 45.
[b] Published in ASTM BULLETIN No. 155, December, 1948, p. 16.
[c] Published in ASTM BULLETIN No. 156, January, 1949, p. 41.
[d] Published in ASTM BULLETIN No. 156, January, 1949, p. 39.
[e] Mr. Vaux's paper available in duplicated form, also Mr. Hart's notes.
[f] Published in ASTM BULLETIN, No. 159, July, 1949, p. 67.

Publications

Responsibility for the publications of the Society is delegated to the Administrative Committee on Papers and Publications. The report of that committee is attached as Appendix IV; it reviews the activities of the committee and gives interesting information about the publications for the past year as well as some future publications.

The annual volume of the *Proceedings* (1366 pages) and the five Supplements to the Book of Standards (1648 pages) were the major 1948 publications. The ASTM BULLETIN published in six issues comprised a total of 664 pages. Thirteen compilations of standards were printed during the year and together with various special technical publications listed in the committee's report constituted an important part of the Society's 1948 publications.

The most important and certainly the biggest publication problem now in hand is the 1949 edition of the Book of A.S.T.M. Standards, which, as already announced, will be published in six parts. The approximate classification of contents of these parts has been announced to the members, together with the revised scale of charges to members for procuring more than one part of the Book on their membership. This year for the first time the six volumes will be published as a grouping together of separate compilations by making up and printing the individual compilations and overrunning on press the desired number of impressions for the Book of Standards. This will require special methods of paging and indexing.

The 1949 *Proceedings* are expected to exceed in volume those of the preceding year, for while the program on papers developed by the Administrative Committee on Papers and Publications will entail about the same number of *Proceeding* pages as for 1948, the volume of committee reports is larger, as is to be expected from the steady expansion of committee work into new fields.

The expansion of the ASTM BULLETIN from six to eight issues a year, as announced a year ago, is being put into effect as of July 1, 1949. This will mean that for 1949 there will be seven issues; beginning with 1950, eight issues will be published spaced approximately six weeks apart. This change-over has involved adjustment of advertising contracts and modifications of publication procedures in the staff. It is the hope of the Board that the mechanical cost of publishing the enlarged BULLETIN can still be met nearly, if not entirely, by receipts from advertising as had been generally true up to this time.

One of the problems that lies ahead is that of publishing the technical papers and discussions that will comprise the Pacific Area National Meeting to be held next October in San Francisco. The committee in charge has developed an excellent technical program of 70 papers; the majority of these are formal papers, many describing new researches, but a number are rather brief contributions to symposiums on selected subjects. None of the papers will be preprinted, but it is hoped to have mimeographed copies of many of them available at the meeting. While a final decision on method of publication has not been made, it is probable that most of the papers will be issued as separate publications in appropriate groupings in the Society's Special Technical Publication series, with an STP number and identified as part of the *Proceedings* of the meeting. Such STPs would, in accordance with established procedure, be available to members at special prices. The several symposiums will especially lend themselves to that method of publication. Other papers may be published in the ASTM BULLETIN either in full or as extended abstracts. More specific announcement of publication plans will be made later.

A publication development of some interest to the Society is the decision of the American Standards Association to adopt $8\frac{1}{2}$ by 11 in., 6 by 9 in., and $5\frac{1}{2}$ by $7\frac{3}{4}$ in. as standard nominal trim sizes of American Standards to be published by ASA. The inclusion of the 6 by 9 in. size, which is in use for all A.S.T.M. standards as well as those of many other bodies, incorporates our practice into the ASA procedure.

Administrative Matters

Proposed Amendment of By-laws:

The Board of Directors recommends to the Society that the following sentence in Article I, Section 7, of the By-laws dealing with honorary members be changed from its present form, namely, "The number of Honorary Members shall not exceed twenty," to read: "The number of Honorary Members shall be left to the discretion of the Board of Directors."

Until 1945 the number of honorary members was limited to ten. In that year the Society on the recommendation of the then Executive Committee increased the allowable number of honorary members to twenty. Consideration of matters relating to the election of honorary members has led the Board to feel that it will be in the better interests of the Society if the number of honorary members be not limited in the By-laws but left to the discretion of the Board. In making this recommendation the Board wishes to state that it is not its intention greatly to increase the number of honorary members, but it does feel that the bestowing of this honor upon those who merit this distinction will be facilitated if the present limitation is removed from the By-laws as recommended.

As required by the provisions of the By-laws, this proposed amendment has already been printed in the notices for the Annual Meeting and the Board now recommends that the Annual Meeting pass the proposed amendment to the required letter ballot vote of the Society.

Regulations Governing Technical Committees:

Two revisions in the Regulations Governing Technical Committees have been under consideration by the Board of Directors and each have been approved for reference, as required in the procedure, to the chairmen of all technical committees for advice and consultation before final action by the Board. These deal with the following subjects:

Special Procedure for Writing Ultimate Consumer Goods Standards.—After full consideration of all aspects of the problem involved, the Board has approved the following modifications of the Regulations Governing Technical Committees[1] to cover the development of standards in the ultimate consumer goods fields wherever it is not feasible to establish in the entire technical committee the balance of interests between producer and consumer prescribed in the regular procedure. It is the intention that any work on standards for the ultimate consumer shall be handled within the framework of our present committee organization but that special provision should be made for having consideration of such standards in representative committees.

1. Insert at the end of Article I, Section 2 (*g*):

An exception to this rule may be involved in certain actions connected with ultimate consumer goods as set forth in Article III, Section 14 (*c*).

2. Add the following to Article II, Section 9:

(See also Article III, Section 14 (*c*)).

3. Change Article III, Section 14 (*c*) to Section 14 (*d*).

4. Insert the following new Section 14 (*c*):

14 (*c*). In certain cases of actions involving ultimate consumer goods it may not be feasible to establish in the appropriate existing technical committee the balance of interests concerning a particular item of consumer goods as prescribed in Article I, Section 2 (*g*). In such cases where recommendations regarding standards or recommended practices involve ultimate consumer goods, the following special provisions shall apply. The technical committee may refer the matter with proper recommendations to a special subcommittee which shall consist of not fewer than nine members and to which shall be applied (rather than to the technical committee) the balance of interests as prescribed in Section 2 (*g*) including representation of the ultimate consumer. Recommended action by such a subcommittee shall be by not less than two-thirds affirmative vote by letter ballot. Such subcommittee recommendations shall be addressed to the technical committee and shall then be handled as usual under Sections 14 (*a*) or (*b*).

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[1] 1948 A.S.T.M. Year Book, p. 518.

The significant change is embodied in the new Section 14 (*c*) which establishes special provisions there set forth which may be followed by a technical committee where it is not feasible to establish in the entire committee the balance of interests concerning a particular item of consumers goods specified in Article I of the Regulations.

This modification of the Regulations is already in the hands of all technical committee chairmen for their advice, and the amendment will not become effective until the Board has considered such advice.

Numeric Balance of Members of Technical Committees.—Acting upon a proposal of Committee D-2 on Petroleum Products and Lubricants that the present provision in Article I, Section 2 (*g*) of the Regulations concerning the balance between producer, consumer, and general interests be replaced by the provision on this matter that was in effect prior to the adoption of the present wording in 1934, the Board believes that it is desirable to make the following amendment of this portion of the Regulations:

Change the present wording, namely,

> Substantial balance with respect to interest shall exist between the general classifications of members appropriate for various types of standards and no one classification shall have a majority save with the recorded assent of the other classifications. In no case shall the number of producers exceed the combined number of consumers and general interests.

to read as follows:

> On such committees either an equal numeric balance shall be maintained between the producers on the one hand and the consumers and general interests, jointly, on the other hand; or the consumers and general interests may be allowed to predominate in the absence of objection by a majority of the producers. Thus a substantial balance may be permitted to exist between the three general classifications of members on technical committees.

For ready reference, following is the wording of this provision of the Regulations that existed prior to 1934:

> On such committees either an equal numeric balance shall be maintained between the producers on the one hand, and the consumers and general interests, jointly, on the other hand; or the consumers and general interests may be allowed to predominate by majority vote of the producers.

The Board has concluded that the proposed wording is to be preferred as indicating more directly the equality of representation between producers and non-producers that is basic in the philosophy of A.S.T.M. committee work. An objection to the adoption of the earlier wording, in that it required an actual vote of producers in order that consumers and general interests may be allowed to predominate on a committee, is obviated in the revised wording by providing that such preponderance of consumers and general interests may exist in the absence of objection by the producers. In view of the conditions that exist in the work of many committees where substantial balance between producers, consumers and general interests is found to be a desirable feature of the committee organization, the concluding sentence of the proposed amendment has been included to point out that such balance between these interests may be permitted to exist under the revised Regulations.

This revision of the Regulations was acted upon at the May meeting of the Board and has just been referred to the technical committee chairmen for advice and consultation, not to become effective until such advice has been received and considered by the Board, concerning which formal announcement will be made.

Headquarters Staff:

Further progress has been made during

the year in enlarging the headquarters staff to meet the work-load imposed by growing technical, publication, and administrative activities. During the latter half of 1948, the staff additions mentioned in last year's report as authorized were made, namely, a young technically trained man to work on development of membership and publication sales under the Assistant Secretary, a stenographer in the same department, and an additional bookkeeper in the finance department. In January, 1949, a young engineer was engaged for the corrosion test-site program already mentioned and since May 1 has been devoting half his time to regular staff work on the general Society salary roll. In this latter capacity he will engage primarily in staff service to technical committees, especially those working in the corrosion and related fields. A new stenographer in the editorial department and an assistant shipper bring the staff as of this date to 52, of whom 13 are on the administrative and technical staff and 39 on the secretarial and clerical staff—an increase of six during the year. In addition, several clerks and stenographers are employed from time to time on a part-time basis to meet peak load conditions.

Some staff expansion in the editorial department beyond that above mentioned has been provided for in the 1949 budget.

Society Headquarters:

The Society Headquarters and its appointments are well suited to the requirements of the members and committees of the Society and to the daily work of the staff. Many have been the compliments of visitors, and the members who have used the meeting and other facilities frequently express their gratification in the Society's having such a fine building of its own as its headquarters. During the calendar year 1948 there were 93 committee meetings and conferences held in the building, including four meetings of other organizations, to whom the Society is always pleased to extend this courtesy.

A few minor alterations have been found advisable, particularly one to enlarge the accounting room by closing a little-used entrance and eliminating a corridor. Repairs have been practically nil, although some outside painting and rebuilding of a portion of the roof have been done. These are all charges against Headquarters' Occupancy Expense in the general budget.

Financial Aspects.—Later in this report, in the section on finances and in the auditors' report covered in Appendix I, is given full information regarding the operations of the Building Fund through which the purchase of the headquarters was made. The headquarters building is carried on the balance sheet as an asset after depreciation of $175,818.12. The building is nearly clear of indebtedness, there being only a note payable to General Funds of $14,500 as of May 31, 1949. Provision is made in the general budget under Headquarters Occupancy Expense to pay off this loan at the rate of approximately $1130 a year, but it is hoped that further contributions to the Building Fund will make possible a more rapid reduction of that indebtedness.

Another item of interest is that the cost of operating the headquarters building, including full depreciation charges and portions of staff salaries chargeable to management and maintenance service, is estimated for 1949 at about $2.25 per sq. ft., which represents an "equivalent rent" considerably less than for comparable facilities elsewhere in Philadelphia.

Award of Merit:

The Board of Directors has decided to establish an A.S.T.M. Award of Merit as a means of recognizing individuals who have rendered distinguished service to the Society. The nature of the award and the rules for selecting those to whom it shall be granted are set forth in the following statement:

A.S.T.M. AWARD OF MERIT

1. *Establishment of Award.*—The Society shall establish an "Award of Merit" which may be granted annually at times and places determined by the Board of Directors, to individuals for distinguished Service to the Society as hereinafter provided.

2. *Basis of Award.*—Any or all of the following types of service shall be considered as the basis for the Award of Merit:

(*a*) Long active productive service in A.S.T.M. committee work.

(*b*) Marked leadership in technical, administrative, or special committee or society activities.

(*c*) Outstanding contribution in the form of research, development of apparatus, or test methods and procedures not specifically recognized or duplicated by any of the other Society awards.

(*d*) Publication of papers that have been of special benefit to the work of the Society or of a committee.

(*e*) Outstanding activity or service that has particularly advanced the Society's prestige, standing, or interest.

(*f*) Any distinguished service to the Society not herein otherwise specifically provided for.

3. *Number of Awards.*—The number of awards granted in any one year shall not exceed one per 750 members, or fraction thereof.

4. *Method of Selection.*—

(*a*) The awards shall be granted by the Board of Directors on recommendation of a special "Award of Merit" Committee of five to be appointed annually by the President, with approval by the Board, on or before January 1 of each year. One member of the Committee shall be from the Board of Directors, to serve for one year. The term of the other four members shall be staggered, and of 2 years' duration.

(*b*) One nomination, accompanied by an appropriate citation, may be made annually (but not necessarily need be made annually) by each technical committee, by its Advisory Committee, or by a special committee appointed by the Chairman or appointed by the Advisory Committee.

Other nominees may be selected by the "Award of Merit" Committee from members participating in other areas of the Society's work.

(*c*) Provided qualified candidates are available, it is the intent that the awards made annually from among technical committee members be equitably distributed among the several general committee groups A, B, C, D, and E.

(*d*) All nominations for the Award of Merit shall be in the hands of the Executive Secretary of the Society for consideration by the "Award of Merit" committee not later than February 1 of each year.

5. *Form of Award.*—The "Award of Merit" shall consist of an appropriate certificate, duly authenticated, bearing in suitable manner the name of the Society and the name of the award in such form and manner as may be designated and approved for this purpose by the Board. A special "Award of Merit" pin or button, appropriately designed, shall be made optionally available for purchase by those to whom the award is granted.

It is planned to make the first such awards in 1950.

Harold deWitt Smith Memorial Award:

The Board is pleased to be able to record in this report that the Society's Committee D-13 on Textile Materials has been selected to administer the award of the Harold deWitt Smith Memorial Medal for Achievement in the Science and Utilization of Textile Fibers. This award has been established by the Fabric Research Laboratories, Inc., a member of the Society, to commemorate the memory of the late Harold deWitt Smith, who was an outstanding technician in the textile field, an active member of Committee D-13, and the Marburg Lecturer in 1944 on "Textile Fibers—An Engineering Approach to an Understanding of Their Properties and Utilization." Rules governing the establishment and administration of the award have been set up by the officers of Committee D-13 in conference with the donor and have been published for information of all concerned in the ASTM BULLETIN and in various textile journals.

Dudley Medal Award:

In view of the increase in the number of papers that must be reviewed each year by the Committee on Dudley Medal Award and the advisability, as shown by experience, of providing some measure of continuity on the committee in successive years, it has been decided to enlarge the committee from three to six members with the members serving for three-year terms on a rotation basis. The Board will designate the chairman of the committee each year from one of the two senior members. The committee will also be appointed in June of each year permitting an earlier start on its work.

Exhibits of Apparatus:

Questions having arisen regarding the exhibiting of commercial testing equipment either at committee meetings or in connection with sessions of an annual meeting when the ASTM Exhibit of Testing Apparatus and Equipment is not being held, the Board has decided to permit the exhibit of commercially available apparatus on such occasions providing the exhibitor will pay a suitable charge as in the regular Society exhibit. However, if a group desires to exhibit apparatus developed privately and not available commercially and is prepared to set up such an exhibit, no charge would be made for such an arrangement.

Membership

On June 1, 1949, the membership of the Society totaled 6620, compared with a total of 6438 on June 1 one year ago. Statistics showing gains and losses in various classes of membership are shown in the following table:

Class of Membership	Membership		Losses				Additions		Total		
	June 1, 1948	June 1, 1949	Resignations	Dropped	Death	Transfer	Transfer	Election	Loss	Gain	Increase
Honorary	16	18	...	..	1	..	3	...	1	3	2
Perpetuity and Life	12	11	...	..	1	..	..	...	1	..	1[a]
Sustaining	211	217	4	..	..	2	6	6	6	12	6
Company, Firm, etc.	1654	1625	73	17	..	25	9	77	115	86	29[a]
Individual, etc	4435	4627	219	83	34	10	35	503	346	538	192
Junior	110	122	6	6	..	16	..	40	28	40	12
Total	6438	6620	302	106	36	53	53	626	497	679	182
Student	577	589	33	268	..	23	..	336	324	336	12

[a] Net loss.

It will be noted that 626 new members were elected, compared with 644 for the preceding year. But with slightly fewer new members, there nevertheless was a greater net increase due to fewer losses from resignations, delinquency and deaths. The net increase of 182 for the year is about one-third greater than the net increase of 125 for the preceding year.

It is encouraging that in contrast to considerably fewer members through the first quarter of 1949 the months of April and May have been among the best the Society has had for new members.

Through May, the five-month figure for new members was 384, which is just ahead of the corresponding figure for 1948. This good showing for these past two months is in part due to considerable promotional effort which the Board has felt should be given to membership work.

In the procurement of new members, the activities of our Membership Committee and of other members of the Society should be noted. Many of our members have been very helpful in suggesting the names of individuals and companies who should find membership of benefit, and many new members have resulted from such help. The Board is very appreciative of these efforts.

Sustaining Members:

There have been 12 new sustaining members acquired, and there were six losses, two of these being transfers to company membership. The 12 new sustaining members are:

Burroughs Adding Machine Co.
California Research Corp.
The Colorado Fuel and Iron Corp.
Continental Oil Co.
Dominion Bridge Co., Ltd.
General Petroleum Corp.
Interchemical Corp.
The Glenn L. Martin Co.
Mid-Continent Petroleum Corp.
Pennsylvania-Dixie Cement Corp.
The Permanente Metals Corp.
Southern Pacific Co.

50-Year Members:

There are ten individuals and companies as noted below that have been connected with the Society continuously for 50 years. Eight of these memberships date from 1898 when the forerunner of A.S.T.M. was the American Section of the International Association for Testing Materials. Though the Society was not officially incorporated until 1902, it has been deemed fitting to recognize the year 1898 in connection with the awards to long-time members. This year, 50-Year Certificates of appropriate design will be awarded for the first time. The members thus to be recognized are as follows:

American Foundrymen's Society (1898)
Bethlehem Steel Co., Inc. (1898)
Booth, Garrett & Blair (1898)
Carnegie-Illinois Steel Co. (1898)
Allan W. Dow (1898)
Robert W. Hunt Co. (1899)
Franklin Institute (1898)
William K. Hatt (1898)
The Lowe Brothers Co. (1899)
William Mueser (1898)

40-Year Members:

Since the plan of awarding certificates commemorating forty years of continuous membership in the Society was established, 138 such certificates have thus far been awarded and this year the following 20 companies and individuals have qualified:

Bird and Son, Inc.
George W. Borton
Everett W. Boughton
Joseph Brobston
Commonwealth Edison Co.
Electrical Testing Laboratories, Inc.
W. H. Fulweiler
General Electric Co., River Works
Heppenstall Co.
The Midvale Co.
Phelps Dodge Copper Products Corp., American Copper Products Division
Raymond Concrete Pile Co.
Schenectady Varnish Co., Inc.
The Sherwin-Williams Co.
Herbert Spencer
Tulane University of Louisiana
Isaac Van Trump
Western Electric Co., Inc., Hawthorne Works
Westinghouse Air Brake Co.
Alfred H. White

Deaths:

The Society has lost the following 35 members through death:

	Date of Membership
Allison, Fred G.	1937
Altieri, V. J.	1934
Ashworth, Joseph A.	1937
Broadhurst, W. H.	1899
Clark, M. M.	1937
Ebberts, Alfred R.	1930
Edwards, Warrick Rigeley	1902
Elphinstone, Lewis M.	1941
Ferguson, Lewis R.	1909
Fry, Lawford H.	1905
Gibson, A. B.	1940
Guy, W. R.	1937
Hyatt, Charles S.	1947
Jackson, Lawrence B.	1946
Kerlin, Ward Dix	1919
Kittredge, Harvey G.	1903
Lehon, Tom	1923
Macht, Maurice L.	1945
Marlies, Charles A.	1932
Mason, Frank H.	1931
Mayo, Marion S.	1944
Paterson, Clifford C.	1918
Powers, Frank T.	1939
Quimby, Henry H.	1903
Seiler, J. F.	1933
Shankland, Archibald D.	1934
Shuman, Jesse J.	1902
Siegel, Harold H.	1947
Solger, L. L.	1926
Thompson, Sanford E.	1904
Thorpe, James B.	1929
Tilton, Henry B.	1912
Tompkins, Haldan M.	1935
Weber, Charles G.	1948
Winder, J. Z.	1943

In addition to the above, the following representatives of company members of the Society passed away:

H. H. Craver, Pittsburgh Testing Laboratory
John L. Foulke, A. & M. Karagheusian, Inc.
Henry C. Frey, Patek Bros., Inc.
William Gaertner, Gaertner Scientific Corp.
Grover C. Holder, Foster Wheeler Corp.
Howard H. Leh, Keystone Portland Cement Co.
J. M. Lurie, Rogers Corp.
D. H. Meloche, American Radiator and Standard Sanitary Corp.
R. W. E. Moore, National Electric Products Corp.
J. Morley Zander, Sand-Lime Brick Assn.

From the dates of membership for the individual members it will be noted that several had been affiliated with the Society continuously for over forty years. In the early years of the Society Messrs. Broadhurst, Edwards, Fry, Quimby, Shuman, and Thompson were very active and some of the men continued to be so until the past few years; in fact, Mr. Thompson for whom the Sanford E. Thompson Award is named in recognition of his outstanding work in Committee C-9 and as its first Chairman, attended the 1948 Annual Meeting. Mr. Quimby had been a member of the A.S.T.M. Board of Directors, and Mr. Shuman was also a former officer of the Society and an Honorary Member. Lawford Fry rendered distinctive service to A.S.T.M. not only in the field of steel in which he was an authority but in numerous other capacities. He also was a former member of the Board.

V. J. Altieri, who served on several technical committees, notably D-3 on Gaseous Fuels, was very active in the work of the New England District and was the Chairman of its Council when he died. Prof. Charles A. Marlies did a great deal to stimulate interest in the Society on the part of his numerous students at the City College of New York. Charles G. Weber, an authority in the field of paper and paper testing, was a most active member of Committee D-6 on Paper and Paper Products, and also of Committee D-10 on Shipping Containers. M. L. Macht gave valuable service to Committee D-20 on Plastics.

A number of the representatives of company memberships including H. H. Craver, William Gaertner, Grover C. Holder, Howard H. Leh, and R. W. E. Moore, rendered valued services to the Society in various ways.

In noting the deaths of these men, the Board of Directors wishes to record its appreciation for the efforts of all of them in supporting and advancing A.S.T.M. activities.

Finances

Report for the Fiscal Year 1948:

The annual statement of the finances of the Society is presented in the form of the report of the auditors for the fiscal year January 1 to December 31, 1948, which appears in Appendix I. The report gives the balance sheet of assets and liabilities, including general funds, building fund, and other special and designated funds; a statement of receipts and disbursements classified into "operating" (budgeted) and "nonoperating"; details of the building fund and of special funds; and investments of Society funds.

Total operating receipts were $520,554.62, the largest in the Society's history. Of this amount receipts from dues and entrance fees were $199,891.76 or 38.4 per cent; receipts from sales of publications were $269,951.60 or 51.9 per cent; receipts from miscellaneous sources consisting principally of advertising, interest and dividends, registration fees, and exhibit, total $50,711.26 or 9.7 per cent. Receipts from publication sales were at an all-time high and reflect strong demand throughout the year for the Book of Standards and Supplements and for the various compilations of standards. It is significant that approximately 84 per cent of publication sales are accounted for by publications growing out of our standardization work, the remaining 16 per cent comprising sales of *Proceedings*, technical papers, BULLETIN, and various special and miscellaneous publications. This shows strikingly the value of the Society's publications as a major source of operating income, without which it would be impossible within the existing dues structure to render to the members the services that are now given.

Operating disbursements with all current bills paid (as detailed in the auditors' report) and including $20,000 placed in the reserve for the next Book of Standards were $459,427.25. Of this amount $196,879.90 (including the above-mentioned reserve) was spent for publications and $154,273.73 for salaries, comprising about 76 per cent of the total. (A year ago this ratio was approximately 80 per cent.) The remaining disbursements of $108,273.62 were divided among items of general office expense, expense of technical committees and district councils, meetings, headquarters occupancy (equivalent rent), employees retirement fund, and miscellaneous items.

The usual payment into the principal of the A.S.T.M. Research Fund of one-half of the current entrance fees of about $2500 was deferred, as was also done a year ago, the Board feeling that the monies involved can be used at the moment to better advantage in support of expanding staff activities.

The difference between operating receipts and disbursements constitutes a favorable operating balance of $61,127.37, which is nearly 12 per cent of current receipts, compared to deficits of $27,911.11 in 1946 and $2322.60 in 1947. In effect this has been made possible by the increase in dues effective January 1, 1948, and the sustained publication sales, and provides the Society with funds to apply to 1949 operations, to which reference is made below.

An informative analysis of current receipts and disbursements can be made on the basis of the "income dollar" and how it was used. Thus, of each dollar of current receipts in 1948,

37.4 cents came from dues,
1.0 cent from entrance fees,
51.9 cents from publication sales,
4.2 cents from advertising,
1.9 cents from the exhibit,
1.3 cents from interest, and
2.3 cents from miscellaneous sources.

We used this income dollar by spending

- 35.9 cents for development and publication of standards and reports,
- 17.6 cents for research, papers and discussions, and
- 34.8 cents for administration—membership and finances, meetings, sales expense, certain publications, promotional activities, etc.,—leaving
- 11.7 cents over for surplus account available for Society operations.

The auditors' report shows total assets in all funds (general funds, building fund, and special and designated funds) of $584,943.65. The report also includes a summary of the comparative financial position of the Society for the past five years. The surplus in the General Funds account on December 31, 1948, was $227,160.50 compared to $157,418.09 a year ago, an increase of $69,742.41. Most of this, of course, comes about from the favorable operating balance of 1948. Other contributing factors are profit on sale of investments and improved position in accounts receivable *versus* accounts payable. While this increase in surplus is, of course, a gratifying development, the ratio of surplus to operating disbursements at current levels is only about 50 per cent; or expressed in another way, the surplus is equivalent only to six months' operations. The Board of Directors would like to strengthen this surplus position and has the matter under consideration.

Building Fund.—The auditors report also includes a statement of cash receipts and disbursements in the Building Fund as well as a balance sheet for the Fund as of December 31, 1948. The final cost of purchasing and establishing the Society Headquarters can now be stated as $184,518.12, towards which there has been received a total of $166,407.12 in contributions from members—a truly splendid and inspiring showing. Other receipts during the life of the Building Fund are shown in the report. The balance of mortgage on the property due December 31, 1948, has been paid off, for which purpose a further loan from A.S.T.M. General Funds to the Building Fund of $7000 was made as indicated. This results in an indebtedness in the Building Fund of $17,000 as of December 31, evidenced by a 4 per cent note payable to General Funds.

The auditors' report also shows that there was paid into the Building Fund from General Funds of the Society the sum of $5500 as reserve for depreciation, this constituting a charge in the general budget against headquarters occupancy expense. This added to a previous payment of $3200 sets up a depreciation reserve of $8700, so that the Headquarters Building is now carried as a depreciated asset of $175,818.12.

While not strictly a part of the report for the fiscal year 1948, it may be mentioned here that further contributions to the Building Fund received in the first five months of 1949 have made it possible to repay as of May 31, 1949, $2500 of the above-mentioned $17,000 note, reducing that indebtedness to $14,500.

Investments.—Investments of Society funds as of December 31, 1948, are given in the auditors' report, both book and market values being shown. As of that date the book value of all investments was $263,779.30; the market value of these investments was $238,101.14, a depreciation of approximately 10 per cent. On the basis of market values 71.9 per cent of investments were in bonds, 9.2 per cent in preferred stock, and 18.9 per cent in common stocks; Government bonds constituted 62.5 per cent of all securities.

The following changes during the fiscal year in the investment portfolio are noted:

GENERAL FUNDS

Bought	*Cost*
Federal Intermediate Credit Bank Debentures	$24 600.00
$20 000 U. S. Treasury Bonds 2%, 1949–51	20 275.00
	$44 875.00

Sold	*Received*
19 shares American Cyanamid Co. 5% Cum. Pfd. (called)	$200.30
100 shares Atlantic Refining Co. Common	4 263.79
100 shares S. S. Kresge Co. Common	3 716.25
100 Mathieson Chemical Corp. Common	3 661.10
75 shares J. C. Penney Co. Common	3 473.57
60 shares Texas Co. Common	3 795.08
50 shares U. S. Gypsum Co. Common	5 281.00
	$24 391.09

RESEARCH FUND

Bought	*Cost*
Federal Intermediate Credit Bank Debentures	$5 400.00

Sold	*Received*
100 shares Ohio Oil Co. Common	$3 710.85
16 shares U. S. Gypsum Co. Common	1 689.90
	$5 400.75

BUILDING FUND

Sold	*Received*
$6500 U. S. Treasury Bonds 2½, 1967–72	$6 512.19

The profit on sale of common stocks reported above in General Funds was $7313.66 and in the Research Fund, $2272.87. A loss of $89.41 was involved in the sale of the Treasury Bonds in the Building Fund.

No account has been taken in the accompanying financial statement of the assets of the Society in the form of publications in stock. An inventory of the principal technical publications as of May 1, 1949, may be summarized as follows:

Year Book (1948)	58
Proceedings (All back copies and incl. 1948)	3 660
Index to Proceedings	1 002
1946 Book of A.S.T.M. Standards	
Part I-A	610
Part I-B	828
Part II	767
Part III-A	280
Part III-B	816
1947 Supplements to Book of Standards	
Part I-A	1 227
Part I-B	825
Part II	981
Part III-A	1 229
Part III-B	1 040
1948 Supplements to Book of Standards	
Part I-A	1 229
Part I-B	1 275
Part II	1 109
Part III-A	1 261
Part III-B	1 243
A.S.T.M. Methods of Chemical Analysis	1 008
Compilation of Standards	20 057
Selected Standards for Students	17 073
Symposiums and Special Reprints	68 412
Reprints of Standards (approximate)	150 000
Index to A.S.T.M. Standards (1948)	4 280
Radiographic Standards	25

1949 Finances:

The current year, being the third year in the triennial publication period 1947–48–49, is one in which disbursements are normally expected to exceed receipts, since disbursements include the principal costs of the new triennial Book of Standards and receipts are reduced by the lessened volume of sales of the current Book and its Supplements. It will be seen from what follows that 1949 conforms to this pattern inasmuch as operating receipts are estimated at less than operating disbursements.

In preparing the budget for 1949 operations, the Board has estimated current receipts at $488,000, made up of $207,000 from dues and entrance fees, $237,500 from publication sales, and $43,500 from receipts from miscellaneous sources, principally advertising, interest and dividends, and registration and other fees.

The budget of disbursements has been fixed at $521,250. The two principal items are, as usual, cost of publications and salaries. The budget for publication is $213,750, which takes as full account as possible of the growing size of the Society's publications and makes allowance for increases in printing costs that became effective early in 1949. Provision is made for meeting most of the cost of the 1949 Book of Standards from current income and the $40,000 Book of Standards Reserve, leaving a sum roughly estimated at $30,000 to be paid from income in 1950 when the books will be completed. The salary budget of $170,000 provides for certain expansion of staff necessitated by the constant growth of technical and administrative work.

In the remaining sections of the budget provision has been made for meeting the normal operating expenses of the Society. The sum of $7000 has been budgeted for expenses of the Pacific

Area National Meeting in this year; this does not include the cost of publishing papers, which will constitute a 1950 expenditure. The sharp increase in postal rates has added approximately $9000 to the Society's operating expenses this year.

Thus the budget as set up anticipates an operating deficit of $33,250. It is hoped, of course, that the estimates are conservative and that actual operations for the year may be balanced or at least that the deficit may be much less. Such deficit as may be incurred will be met from surplus from the previous year's operations.

To complete reference to 1949 finances thus far this year, it is noted that during the first five months the following securities were purchased for the General Funds: 50 shares Gulf Oil Corp. common, 100 shares Ohio Oil Co. common, 100 shares Philadelphia Electric Co. common and 100 shares Chase National Bank common, totaling $11,469.23, and $5000 Federal Intermediate Credit Bank Debentures. On June 1, $30,000 Federal Intermediate Credit Bank Debentures matured and the proceeds have been invested in U. S. Savings Bonds, Series G, $24,600 for General Funds and $5400 for the Research Fund.

The total book value of Society investments as of May 31, 1949, in all funds was $280,248.53. The Society's cash balance in General Funds as of the same date was $241,690.93.

Retirement Plan for Employees

During the year three employees, out of five newly eligible, joined the Retirement Plan, bringing the total number of participants to 28 out of 37 eligible employees. All of the eligible men on the staff are participating, and most of the nine women who have not joined the plan are new and younger employees. In addition, new retirement policies were taken out for five employees to bring their retirement incomes closer to those specified in the Plan.

An important amendment to the Plan was adopted by the Board, effective on the anniversary date of May 3, 1949. Heretofore the Plan has required each employee to contribute $2\frac{1}{2}$ per cent of entire salary, including any portion over $5000, whereas the formula for retirement benefit is based upon a $5000 salary maximum. The purpose of the earlier provision was to keep the Society's costs down, since the funds available for this purpose when the Plan was started eleven years ago were very limited. The Board feels that this somewhat inequitable situation can now be rectified by limiting employees' contributions to $2\frac{1}{2}$ per cent of salary up to $5000, crediting back contributions in excess of the $2\frac{1}{2}$ per cent of the $5000 maximum in the case of five employees affected on the premise that the employee has purchased therewith additional retirement income on a personal basis, and making up the deficit created by this credit by Society contributions to provide equivalent retirement income. The Plan has accordingly been amended and the adjustments made as of 1949.

The Society's total contribution in premium deposits for retirement policies for the above-mentioned 28 employees is at the annual rate of approximately $13,750, which is roughly 8 per cent of the present salary roll and $2\frac{1}{2}$ per cent of estimated current disbursements. The total of employees' annual contributions, including insurance benefits which most of them have elected, is approximately $3250.

Cooperative Activities

The Society's many cooperative relations with other organizations have continued during the year along lines of well-established policy and mention will be made here only of a few of the more significant happenings and certain new developments during the year.

Cooperation with the Federal Specifications Board and its various technical committees has been continued to the mutual advantage of Federal and A.S.T.M. specification work. Contacts at the staff level are maintained which serve to keep the staffs and through them the committees of the two organizations informed of important developments in specification activities. Committees of the Society continue to review many Federal specifications in draft form.

The A.S.T.M. Ordnance Advisory Committee met with officers and staff of the Research and Development Branch of the Ordnance Department in October, 1948. Advisory services that the committee has been rendering on plastics, adhesives, and rubber were reviewed. Advisory services relating to tests for engine antifreezes have been arranged through the Society's Committee D-15 on that subject. The Ordnance Department has under preparation a certain type of specification for steel parts for ordnance materiel, concerning which the advice of the Ordnance Advisory Committee will in due time be requested. Some problems relating to low-temperature and flexible barrier packaging materials have been discussed.

Upon invitation from the Munitions Board, Neil A. Fowler has been designated as the Society's representative on the Packaging, Storage, and Materials Handling Industry Advisory Committee of the Munitions Board. Mr. Fowler is also a member of the above-mentioned Ordnance Advisory Committee thus tying in the Society's advisory services to these two government groups. The appointment was made after consultation with the chairman of Committee D-10 on Shipping Containers.

The Technical Secretary participated in a Seminar on Industrial Standardization held in Washington on March 17, 1949, under the auspices of the Industrial College of the Armed Forces. The purpose of the seminar was primarily to furnish information regarding the manner of operation of such standardizing bodies as the A.S.T.M., the American Standards Association, and the Aircraft Industries Association. Discussion in the seminar brought out the extent of cooperation of the Armed Forces in A.S.T.M. committee work.

The Society has joined with the Society for Applied Spectroscopy in forming a Joint Committee on Nomenclature in Applied Spectroscopy and has appointed a number of members of Committee E-2 on Spectrographic Analysis as A.S.T.M. representatives on the joint committee. The personnel of the joint committee was published in the March issue of the ASTM BULLETIN.

In response to an invitation from the Division of Cellulose Chemistry of the American Chemical Society, arrangements are being made to coordinate certain standardization activities of that Division with work of several A.S.T.M. committees interested in cellulose materials by appointment of A.S.T.M. representatives on the Committee on Standards and Methods of Testing of the A.C.S. Division.

The Society is holding a joint meeting with the American Statistical Association in connection with the annual meeting of that organization in New York next December. The meeting will deal with the subject "Statistical Design of Engneering Tests" and will serve to bring to bear on a problem of great significance to engineers in the field of testing the notable contributions of the mathematician in the field of statistics.

For some years the Society has participated in the activities of the American Documentation Institute, a non-profit corporation for the promotion and development of documentation in scholarly and scientific fields, the members of which are nominated by agencies in those fields. The Society has been such a nominating agency, with Roy W. Crum as its representative. This arrangement has not involved any financial support of the Institute. Recently the organization of the Institute has been placed on a more formal basis and the Board of Directors has accepted for the Society an invitation to continue participation in the work of the Institute as a contributing member at $50 annually.

American Standards Association:

The Society's technical relationships with the work of the American Standards Association come largely under the responsibility of the Administrative Committee on Standards, and the report of that committee (see Appendix II) discusses a number of matters that have developed during the year.

On the administrative side the Board of Directors has continued to follow the discussions that are taking place in the American Standards Association concerning the matter of incorporation of that organization. On August 2, 1948, the Association was incorporated under the laws of the State of New York pursuant to a vote of a conference of the member bodies of ASA favoring immediate State incorporation with the understanding that efforts looking to federal incorporation would be continued. A bill for such incorporation was introduced in both the Senate and House of Representatives of the last Congress but died with the adjournment of that Congress. A number of modifications in that bill have been proposed by ASA and are being studied by your Board of Directors. It has been agreed that before any further bill for incorporation is introduced in Congress, draft copies will be distributed to the member bodies of ASA.

In the report a year ago the Board mentioned that amendments to the By-laws of ASA were under consideration that would permit correlating committees of the Association to serve as sponsors for standardization projects. These proposed amendments have since been adopted.

The Conference of Staff Executives of Member Bodies of ASA, of which the Executive Secretary was chairman at the time, held a meeting in October, 1948, in conjunction with the annual meeting of ASA, devoted to the subject "Practical Answers to a Practical Question—What Good Are Standards?" An account of the meeting and abstracts of the addresses appear in the March, 1949, issue of the ASTM BULLETIN. At this meeting the name of the Conference was changed to Conference of Executives of Organization Members, American Standards Association, Inc., and the Executive Secretary retired as chairman, continuing on the Executive Committee of CEOM.

J. R. Townsend was reappointed as one of the Society's representatives on the ASA Standards Council for a term of three years beginning January 1, 1949, the other representative being F. M. Farmer. J. H. Foote and the Technical Secretary were retained as alternates on the Council for the current year. Mr. Townsend was also reappointed as Society representative on the Mechanical Standards Committee, and A. G. Ashcroft reappointed on the Advisory Committee on Ultimate Consumer Goods, each for a term of two years.

International Activities:

The principal contacts of the Society with international activities have been in connection with various standardization projects being undertaken in the International Organization for Standardization (ISO). Brief reference to the status of a number of these projects is contained in the report of the Administrative Committee on Standards (Appendix II) to which reference should be made. The Society continues to maintain a continuous contact with a number of the standardizing bodies of other countries through exchange of standards for review and comment, exchange of publications, and in other ways.

An important project with the British Institute of Petroleum has been under development for a year or more, namely, publication of a joint ASTM-IP Manual of Oil Measurement Tables. Negotiations for the Society are being carried on by Committee D-2 on Petroleum Products and Lubricants.

As noted a year ago, the Society participated in the International Conference on Soils held in Holland last June, being officially represented by Professors E. J. Kilcawley and F. J. Converse. These representatives submitted a formal report to the Board and a more technical report to Committee D-18 on Soils for Engineering Purposes. The Society has subscribed to a set of the Proceedings of the Conference for its library.

Respectfully submitted on behalf of the Board of Directors,

RICHARD L. TEMPLIN,
President.

C. L. WARWICK,
Executive Secretary
June, 1949.

APPENDIX I

REPORT OF THE AUDITORS FOR THE FISCAL YEAR JANUARY 1 TO DECEMBER 31, 1948

Philadelphia, January 5, 1949

Mr. C. L. Warwick, *Executive Secretary*
AMERICAN SOCIETY FOR TESTING MATERIALS
Philadelphia, Pennsylvania

Dear Sir:

We have examined the books and accounts of the American Society for Testing Materials for the year ended December 31, 1948. We did not make a detailed audit of all transactions, but made tests to the extent we considered appropriate in determining the accuracy of the records. Accounts receivable were not verified by correspondence with debtors. The investments owned by the Society were examined by us; all income from investments for the period under review was properly accounted for.

We have prepared and submit herewith balance sheet as of December 31, 1948, statement of cash receipts and disbursements for the year ended that date, and other supporting schedules, all of which are in agreement with the records of the Society.

In our opinion, these statements, with notes thereto, present fairly the financial position of the Society at December 31, 1948 and the results of its operations for the year ended that date.

Respectfully submitted,

John Heins & Co.

BALANCE SHEET AS OF DECEMBER 31, 1948

(Including Special and Designated Funds)

ASSETS

General Funds:			
Current: Cash	$94 441.65		
Less Check No. 535 as of December 16, 1948 (estimated cost of 1948 Proceedings and 1948 Supplements to 1946 Book of Standards)	43 750.00		
		$50 691.65	
Investments (Market Value $174 431.60)—Cost		191 497.99	
Accounts Receivable		29 748.11	
Note Receivable Building Fund		17 000.00	
			$288 937.75
Furniture and Fixtures (depreciated book value)			17 261.45
Total Assets General Funds			$306 199.20
Building Fund:			
Cash		$ 578.22	
Investments (Market Value $8 539.84)—Cost		8 632.83	
Land (Cost)		30 000.00	
Building and construction costs	$154 518.12		
Less Reserve for depreciation	8 700.00	145 818.12	
Total Assets Building Fund			$185 029.17
Other Special and Designated Funds:			
Cash: A.S.T.M. Research Fund	5 477.54		
Dudley Medal and Marburg Lecture Fund	1 505.70		
Richard L. Templin Award Fund	60.46		
Sam Tour Award Fund	37.50		
Committee Funds	22 989.60	30 066.80	
Investments:			
A.S.T.M. Research Fund (Market Value $39 459.90) Cost	45 523.48		
Dudley Medal and Marburg Lecture Fund (Market Value $4 052.50) Cost	6 625.00		
Richard L. Templin Award Fund (Market Value $1 004.68) Cost	1 000.00		
Sam Tour Award Fund (Market Value $1 467.00) Cost	1 500.00		
Committee Funds (Market Value $9 145.62) Cost	9 000.00	63 648.48	
Total Assets, Special and Designated Funds			$93 715.28
Total Assets			$584 943.65

LIABILITIES

General Funds:			
Current: Accounts Payable:			
Committee C-1			$ 149.31
Advance Collections			7 628.47
Total Current Liabilities—General Funds			7 777.78
Life Membership Fund		$3 812.50	
Publication Fund		1 841.80	
Book of Standards Reserve		40 000.00	
Executive Retirement Reserve		10 680.00	
Retirement Fund Reserve		2 926.62	
Reserve for Depreciation of Investments		12 000.00	
Surplus		227 160.50	
			298421.42
Total Liabilities General Funds			$306 199.20
Building Fund:			
Contributions		166 407.12	
Accumulated Income and Profit on Investments		1 622.05	
Note Payable to A.S.T.M. General Funds		17 000.00	
Total Building Fund			$185 029.17
Other Special and Designated Funds:			
A.S.T.M. Research Fund:			
Principal	45 608.10		
Income	5 392.92	51 001.02	
Dudley Medal and Marburg Lecture Fund:			
Principal	6 625.00		
Income	1 501.70	8 126.70	
Richard L. Templin Award Fund:			
Principal	1 000.00		
Income	60.46	1 060.46	
Sam Tour Award Fund:			
Principal	1 500.00		
Income	37.50	1 537.50	
Committee Funds, Unexpended Balances		31 989.60	
Total Special and Designated Funds			$93 715.28
Total Liabilities and Funds			$584 943.65

COMPARISON OF GENERAL FUNDS FOR FISCAL YEARS 1944–1948, INCLUSIVE.

At Close of Fiscal Year	Assets				Liabilities			
	Cash	Investments	Accounts Receivable	Furniture and Fixtures	Accounts Payable	Reserve for Book of Standards	Miscellaneous Funds	Surplus
1944	$42 637.45	$114 237.61	$11 986.97	$6 780.66	$9 009.15	$17 113.98	$37 913.05	$111 606.51
1945	46 058.60	153 718.05	15 033.90	6 641.57	5 432.16	15 000.00	35 982.49	165 037.47
1946	5 100.03	160 383.60	26 150.27	14 964.50	7 270.11	15 000.00	40 117.54	144 210.75
1947	3 930.42	163 690.12	37 218.85	16 405.39	7 755.95	20 000.00	36 070.74	157 418.09
1948	50 691.65	191 497.99	46 748.11	17 261.45	7 777.78	40 000.00	31 260.92	227 160.50

RECEIPTS AND DISBURSEMENTS

FOR THE PERIOD JANUARY 1, 1948 TO DECEMBER 31, 1948

Cash balance, January 1, 1948			$3 930.42

RECEIPTS

Operating Receipts (Budgeted):			
Dues and Entrance Fees:			
Current Dues	$189 704.49		
Past Dues	857.82		
Advance Dues	4 199.45		
Income, Life Membership Fund	175.00		
Entrance Fees	4 955.00		
Total Dues		$199 891.76	
Sales of Publications:			
Book of Standards (Members, addl. parts)	32 362.00		
1946 Book of Standards	50 419.83		
1947 Supplements to Book of Standards	38 349.03		
Methods of Chemical Analysis of Metals	2 677.86		
Compilations of Standards	72 106.35		
Separate Standards	16 547.57		
Selected Standards for Students	11 823.07		
Proceedings	5 890.25		
Spring Meeting Papers	2 818.04		
Bulletin Subscriptions (non-members)	1 844.13		
Special and Miscellaneous Publications	35 113.47		
Total Sales of Publications		$269 951.60	
Miscellaneous:			
Advertising—Bulletin	19 756.71		
Advertising—Index	2 322.50		
Interest and Dividends	6 991.04		
Registration and Other Fees—Meetings	6 623.00		
Exhibit Annual Meeting	9 665.49		
Committee A-1 for Technical Assistant	2 671.32		
ASTM-DCC Reference Fuel Account	1 531.24		
Miscellaneous	1 149.96		
Total Miscellaneous Items		$50 711.26	
Total Operating Receipts (budgeted)		$520 554.62	
Nonoperating Receipts (Not Budgeted):			
Investments Matured or Sold	24 391.09		
Excess Remittances	996.55		
Committee C-1 for Technical Assistant	2 750.00		
Executive Retirement Reserve	300.00		
Joint AIME-ASTM Publication Fund	256.65		
Institute of Petroleum Publications	1 507.40		
Joint Comm. on X-ray Diffraction covering period 1946–47–48	8 694.24		
Total Nonoperating Receipts		$38 895.93	
Total Receipts			$559 450.55
Total Receipts for 1948 and Cash Balance January 1, 1948			$563 380.97

DISBURSEMENTS

Operating Disbursements (Budgeted):			
Publications:			
Year Book	$9 839.97		
1946 Book of Standards	561.65		
1947 Supplement to Book of Standards	6 978.70		
1948 Supplement to Book of Standards	27 064.96[a]		
Compilation of Standards	27 932.11		
Separate Standards	8 323.09		
Selected Standards for Students	8 146.97		
Chemical Analysis of Metals	58.95		
Proceedings	28 856.96[a]		
Preprints	4 835.54		
Spring Meeting Papers	1 677.69		
A.S.T.M. Bulletin	22 820.37		
Circulars to Members	2 939.74		
Index to Standards	5 017.09		
Special and Miscellaneous Publications	21 826.11		
Total Disbursements—Publications		$176 879.90	
Salaries		154 274.73	
General Office Expenses		40 910.44	
Expenses—Technical Committees		11 351.47	
Expenses—Meetings		10 237.12	
Exhibit, Annual Meeting		5 301.61	
American Standards Association		1 000.00	
Traveling Expenses, Administrative and Special Committees		5 612.84	
Headquarters Occupancy Expenses (includes $5500 depreciation on building, elevator, and air conditioning installation)		17 266.73	
Furniture and Fixtures		3 321.98	
Dues, Contributions, Miscellaneous		1 020.75	
Legal Services		1 000.00	
Employees Retirement Fund		11 250.68	
Total Operating Disbursement (Budgeted)		**$439 427.25**	
Nonoperating Disbursements (Not Budgeted):			
Refund of Excess Remittances	996.55		
Investments	44 875.00		
Accrued Interest	99.45		
Technical Assistant Committee C-1	2 770.81		
Expenses Jt. Comm. X-ray Diffraction	4 812.86		
Joint Comm. X-ray Diffraction	9 000.00		
Institute of Petroleum Publications	1 507.40		
Loan to Building Fund	7 000.00		
Loan to Advisory Committee on Corrosion	1 000.00		
Miscellaneous	1 200.00		
Total Nonoperating Disbursements		$73 262.07	
Total Disbursements			$512 689.32
Cash Balance, December 31, 1948			$50 691.65

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[a] These accounts include $43,750.00 representing a check drawn against cost of the 1948 Proceedings and 1948 Supplement to 1946 Book of Standards, but not actually paid on December 31, 1948.

A.S.T.M. BUILDING FUND

DETAILS OF BUILDING FUND CASH RECEIPTS AND DISBURSEMENTS FOR THE PERIOD JANUARY 1, 1948 TO DECEMBER 31, 1948

Cash Balance, January 1, 1948		$6 274.97
Receipts		
Contributions 1948	$2 674.69	
Income from Investments:		
Interest on U. S. Treasury Bonds 2½s 1967–72	369.23	
Proceeds from sale of $6 500 U. S. Treasury Bonds 2½s 1967–72	6 512.19	
From General Funds for Depreciation on Building, Elevator, and Air Conditioning Installation	5 500.00	
Loan from A.S.T.M. General Funds	7 000.00	22 056.11
		$28 331.08
Disbursements		
Architect's Fees	$908.33	
General Contractor	568.00	
Air Conditioning Contract	3 438.28	
Exhaust System for Basement	216.25	
Sound Proofing	521.00	
Interest on Loan from General Funds	100.00	
Reduction of Mortgage—3 quarterly payments of $187.50 each	562.50	
Payment of balance of Mortgage due 12–23–48	21 437.50	
Satisfaction fee	1.00	27 752.86
Cash Balance, December 31, 1948		**$578.22**

A.S.T.M. BUILDING FUND

DETAILS OF ASSETS AND LIABILITIES OF BUILDING FUND AS OF DECEMBER 31, 1948

Assets

Cash Balance, January, 1948				$578.22
Investments:				
$8 500. U. S. Treasury Bonds 2½s 1967–72 at $101.16 (Market Value $8 539.84)—Cost				8 632.83
Property, 1916–18 Race Street, Philadelphia, Pa.:				
Purchase Price	$53 625.00			
Commission to Agent	2 681.25			
Settlement fees, net	197.10			
	$56 503.35			
Allocated to:				
Land			$30 000.00	
Building		$26 503.35		
Construction Costs:				
Architect's fee	11 544.70			
Rent paid to facilitate possession	110.00			
Zoning fees and permits	17.50			
General Contractor	86 933.72			
Air Conditioning	20 749.00			
Elevator	7 548.04			
Air Conditioning Unit	210.00			
Exhaust system for basement	216.25			
Real Estate Agent's Fee	500.00			
Soundproofing	521.00			
Miscellaneous	817.48			
	129 167.69			
Less, Proceeds from sales and salvage of equipment and rentals	1 152.92	128 014.77		
		$154 518.12		
Reserve for Depreciation (provided from General Funds)		8 700.00	145 818.12	175 818.12
Total Assets				$185 029.17

Liabilities and Funds

Contributions			$166 407.12	
Income on Investments:				
Interest on U. S. Treasury 2½s 1967–72		$1 745.78		
Less Interest on Loan from General Funds	$200.00			
Less Loss on Sale of Securities	89.41	289.41	1 456.37	
Profit on Sale of $10 000. U. S. Treasury Bonds			165.68	
Note Payable to A.S.T.M. General Funds			17 000.00	$185 029.17

In addition to the General Funds of the Society the Treasurer had on hand the following funds as of December 31, 1948:

A.S.T.M. RESEARCH FUND

	Total	*Invested*	*Uninvested Cash*
Principal Account:			
Balance, January 1, 1948	$43 335.23	$43 251.36	$83.87
Receipts:			
Sale of Securities		−5 400.75	+5 400.75
Profit on Sale of Securities	2 272.87	+2 272.87	
Disbursements:			
Purchase of Securities		+5 400.00	−5 400.00
Balance, December 31, 1948	$45 608.10	$45 523.48	$84.62
Income Account:			
Balance, January 1, 1948		$4 061.05	
Receipts:			
Interest and Dividends on Investments		1 581.87	$5 642.92
Disbursements:			
Welding Research Council			250.00
Balance, December 31, 1948			$5 392.92

DUDLEY MEDAL AND MARBURG LECTURE FUND

Balance, January 1, 1948			
Principal—Investments (at cost)	**$6 625.00**		
Income—Cash	**1 493.70**	**$8 118.70**	
Receipts			
Interest on Investments		**330.00**	**$8 448.70**
Disbursements			
Honorarium		200.00	
Dudley Medals		77.00	
Electro and Lecture Certificate		45.00	322.00
			$8 126.70
Accounted for as follows:			
Principal—Investments (at cost)		6 625.00	
Income—Cash in bank		1 501.70	$8 126.70

RICHARD L. TEMPLIN AWARD FUND

Balance, January 1, 1948			
Principal—Investments (at cost)	$1 000.00		
Income—Cash	51.96	$1 051.96	
Receipts			
Interest on Investments	25.00		
Contribution from General Funds	30.00	55.00	$1 106.96

Disbursements

Templin Award	25.00	
Cost of Certificate Plate	21.50	46.50
		$1 060.46
Accounted for as follows:		
Principal—Investments (at cost)	$1 000.00	
Income—Cash in bank	60.46	$1 060.46

SAM TOUR AWARD FUND

Balance, January 1, 1948	$1 500.00	

Receipts

Interest on Investment	37.50	$1 537.50

Disbursements

None		
Accounted for as follows:		
Principal—Investments (at cost)	$1 500.00	
Income—Cash in bank	37.50	$1 537.50

COMMITTEE FUNDS

Committee A-1 on Steel	$315.50	
Committee A-5 on Corrosion of Iron and Steel	1 127.05	
Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys	2 435.94	
Committee B-6 on Die-Cast Metals and Alloys	2 565.92	
Committee B-8 on Electrodeposited Metallic Coatings	11.25	
Committee C-1 on Cement	780.73	
Committee C-1 Cement Reference Laboratory	465.04	
Committee C-9 Sanford E. Thompson Medal Fund	946.14	
Committee C-9 on Concrete and Concrete Aggregates	153.32	
Committee C-15 on Manufactured Masonry Units	383.56	
Committee C-18 on Natural Building Stones	176.36	
Committee D-1 on Paint, Varnish, Lacquer and Related Products	436.37	
Committee D-2 on Petroleum Products and Lubricants	228.67	
Committee D-2 D.C.C. Reference Fuel Account	13 569.71	
Committee D-4 on Road and Paving Materials	36.95	
Committee D-5 on Coal and Coke	1 472.74	
Committee D-9 on Electrical Insulating Materials	480.99	
Committee D-12 on Soaps and Other Detergents	178.57	
Committee D-13 on Textile Materials	645.61	
Committee D-13 on Research-Textiles Finishes	238.34	
Committee D-15 on Engine Antifreezes	31.00	
Committee E-3 on Chemical Analysis of Metals	144.39	
Committee E-9 on Fatigue	197.56	
A.S.A. Sectional Committee on Specifications for Cast Iron Pipe and Special Castings	1 541.04	
Detroit District Council	1 195.83	
Philadelphia District Council	373.51	
Pittsburgh District Council	55.50	
Western New York-Ontario District Council	383.14	
Advisory Committee on Corrosion	911.56	
Administrative Committee on Ultimate Consumer Goods	201.55	
Joint Committee on X-ray Diffraction	305.76	
Total Committee Funds		$31 989.60
Accounted for as follows:		
Cash on hand	$22 989.60	
Investments (at cost)	9 000.00	$31 989.60

INVESTMENTS

AS OF DECEMBER 31, 1948

GENERAL FUNDS

Par Value	*Bonds*	*Cost or Book Value*	*Market[a] Value*
$2 000	Associated Electric Co. 4½, 1953	$1 693.50	$1 930.00
4 000	Erie R. R. Co. Gen. Mtg. Income 4½s, 2015	2 832.00	2 740.00
2 000	Hudson Coal Co. S. F. 5s Series A, 1962	1 697.25	1 872.50
3 000	Southern Pacific Deb. 4½s, 1969	2 544.75	2 760.00
13 000	U. S. Savings Bonds, Series G 2½s[a]	13 000.00	12 424.00
4 800	U. S. Treasury Bonds, 2½s, 1967–72	4 800.00	4 826.82
2 000	U. S. Treasury Bonds, 2½s, 1964–69	2 000.00	2 001.25
2 000	U. S. Treasury Bonds, 2s, 1952–54	2 000.00	2 026.25
50 000	U. S. Treasury Bonds, 2s, 1952–54	50 765.63	50 656.25
20 000	U. S. Treasury Bonds, 2s—1949–51	20 275.00	20 137.50
5 000	Walworth Co. 3¼s convertible debentures, 1976	5 496.53	4 537.50
24 600	Federal Intermediate Credit Bank Deb., due 6.1.49	24 600.00	24 600.00
		$131 704.66	$130 512.07
Shares	*Preferred Stocks*		
22	American Airlines Inc., 3½ cumulative convertible	2 244.00	1 182.50
10	American Cyanamid Co., 3½ per cent Series A convertible	1 042.53	1 002.50
25	Colgate-Palmolive-Peet Co., $3.50	2 525.00	2 225.00
100	Murray Corp. of America, cumulative 4 per cent	5 050.06	3 300.00
20	Philco Corp., 3¾ Series A	2 030.00	1 680.00
		$12 891.59	$9 390.00
	Common Stocks		
75	Allis-Chalmers Mfg. Co., no par value	3 316.20	1 987.50
25	American Can Co.	2 122.30	2 040.65
50	American Cyanamid Co., Class B	1 764.25	1 931.25
100	American Rad. & Std. Sanitary Corp.	1 564.32	1 412.50
25	American Tobacco Co.	2 110.12	1 525.00
30	American Viscose Corp.	2 323.58	1 882.50
100	Baldwin Locomotive Works	3 822.00	1 125.00
100	Carpenter Steel Co.	5 426.00	3 125.00
10	Delaware Power and Light Co.	135.00	176.25
75	General Telephone Corp.	2 675.00	1 725.00
300	International Harvester	9 610.00	8 025.00
60	Lone Star Cement, no par value	4 349.42	3 900.00
30	Montgomery Ward Co.	1 813.99	1 575.00
67	Philadelphia Electric Co.	1 185.06	1 381.88
116	Public Service Elec. & Gas Co., avg.	4 369.50	2 334.50
20	United Gas Improvement Co.	315.00	382.50
	TOTAL Common Stocks	$46 901.74	$34 529.53
	TOTAL Common and Preferred Stocks	$59 793.33	$43 919.53
	TOTAL Stocks and Bonds	$191 497.99	$174 431.60

A.S.T.M. BUILDING FUND

Par Value	*Bonds*	*Cost or Book Value*	*Market Value[a]*
$8 500	U. S. Treasury, 2½s, 1967–72	$ 8 632.83	$ 8 539.84

A.S.T.M. RESEARCH FUND

	Bonds		
2 000	Associated Electric Co. 4½s, 1953	1 693.50	1 930.00
1 500	Balto. & Ohio R. R. Gen. & Ref. 5s Series M. 1996	1 511.25	915.00
2 000	Hudson Coal Co. S.F. 5s Series A, 1962	1 697.25	1 872.50
4 500	U. S. Defense Savings Bonds, Series G. 2½s[a]	4 500.00	4 311.00
2 000	U. S. Treasury Bonds 1965–70, 2½s	2 000.00	2 019.38
5 400	Federal Intermediate Credit Bank Deb., due 6.1.49	5 400.00	5 400.00
		$16 802.00	$16 447.88
Shares	*Preferred Stocks*		
30	Allis-Chalmers Mfg. Co. 3¼ cumulative convertible	3 007.22	2 347.50
33	American Airlines Inc. 3½ cumulative convertible	3 366.00	1 773.75
30	Butler Bros., cumulative	3 090.00	2 250.00
12	Consolidated Edison Co. of N. Y. $5	1 234.39	1 299.00
29	Consumers Power Co., $4.50 no par value	2 914.50	3 063.13
20	Philco Corp., 3¾ Series A	2 030.00	1 680.00
		$15 642.11	$12 413.38
	Common Stocks		
100	Allis-Chalmers Mfg. Co., no par value	4 421.59	2 650.00
5	Delaware Power & Light Co.	67.50	88.13
98	General Motors Corp. par $10—gift[b]	6 504.75	5 757.50
20	Montgomery Ward Co.	1 209.33	1 050.00
33	Philadelphia Electric Co.	583.70	680.63
9	Public Service Elec. & Gas Co.	135.00	181.13
10	United Gas Improvement Co.	157.50	191.25
	TOTAL Common Stocks	$13 079.37	$10 598.64
	TOTAL Common and Preferred Stocks	$28 721.48	$23 012.02
	TOTAL Stocks and Bonds	$45 523.48	$39 459.90

DUDLEY MEDAL AND MARBURG LECTURE FUND

Par Value	*Bonds*	*Cost or Book Value*	*Market[a] Value*
$500.00	Balto. & Ohio R. R. Ref. & Gen. Mtg. 6s, Series J., 1995	$550.00	$355.00
6 000.00	Balto. & Ohio R. R. Ref. & Gen. Mtg. 5s, Series G., 1995	6 075.00	3 697.50
		$6 625.00	$4 052.50

RICHARD L. TEMPLIN AWARD FUND

$1 000.00	U. S. Treasury Bonds 2½s, 1967–72	$1 000.00	$1 004.68

SAM TOUR AWARD FUND

$1 500.00	U. S. Defense Savings Bonds, Series G, 2½[a]	$1 500.00	$1 467.00

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[a] Market values were taken from current financial publications as of close of market December 31, 1948, except U.S. Savings Bonds Series G, which are stated at redemption value as of December 31, 1948.

[b] The income from these shares is, by agreement, paid to an annuitant.

COMMITTEE FUNDS

$1 000.00 U. S. Treasury Bonds, 2⅞s, 1955–60	$1 000.00	$1 082.50
2 000.00 U. S. Treasury Bonds, 2½s, 1964–69	2 000.00	2 020.00
3 000.00 U. S. Treasury Bonds, 2½s, 1965–70	3 000.00	3 029.06
3 000.00 U. S. Treasury Bonds, 2½s, 1967–72	3 000.00	3 014.06
	$9 000.00	$9 145.62

GRAND TOTALS, Common stocks	$59 981.11	$45 128.17
GRAND TOTALS, Preferred stocks	28 533.70	21 803.38
GRAND TOTALS, Bonds	175 264.49	171 169.59
	$263 779.30	$238 101.14

APPENDIX II

REPORT OF ADMINISTRATIVE COMMITTEE ON STANDARDS

When the Administrative Committee on Standards was set up with the establishment of the Society's procedure for the approval of tentatives and revisions in the interval between annual meetings, it was rather expected that the use of this procedure would be the exception and that the bulk of recommendations would follow the usual annual meeting procedure. Over the years, however, the procedure involving the Administrative Committee action has been followed to an ever increasing extent so that in recent years the number of recommendations submitted to the Administrative Committee on Standards with respect to tentatives and revisions are almost as large as those submitted at the annual meeting. As a result of actions taken, 25 new tentatives were accepted during the year as well as revisions of 35 tentatives, 14 tentative revisions of standards, 10 standards reverted to tentative, and 1 standard withdrawn. A number of these were acted upon at a meeting of the committee held on September 29, 1948, whereas the remainder were handled by letter.

As a matter of record a list of the recommendations approved appears as an appendix to this report.[1]

A desire for prompt acceptance of technical committee actions has sometimes led to submittal to the Administrative Committee of proposals on which insufficient consideration has been given to negative viewpoints as brought out in the technical committee ballots. In order that Society tentatives may have the full benefit of proper consideration of such negative viewpoints in the technical committees, the Administrative Committee requires an analysis of the committee vote and verbatim quotations of comments of negative voters in connection with recommendations from technical committees. Full compliance with the Administrative Committee's requirements in this respect expedites action on recommendations.

Also to an increasing extent, the Administrative Committee is looked to in connection with the other of its functions. It has, for example, given considerable attention to the character and quality of the Society's standards in general. There has also been quite a number of proposals for the extension of the Society's standardization activities.

EXPANSION OF STANDARDIZATION ACTIVITIES

Of the projects referred to in the report presented a year ago, organization has now been effected of the following committees:

E-12 on Appearance
C-21 on Ceramic Whitewares

The organization meeting of Committee C-20 on Acoustical Materials will be held on May 3, 1949.

The subject of printing inks, referred to in an earlier report, is now being taken up in a new subcommittee organized under Committee D-1 on Paint, Varnish, Lacquer, and Related Products.

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[1] This list is not reproduced here, since the recommendations have all been announced currently throughout the year in the ASTM BULLETIN.—ED.

Porcelain Enamel.—A canvass referred to in the report a year ago resulted in the holding of a conference to consider the desirability of organizing an A.S.T.M. committee in the field of porcelain or ceramic enamel. On the recommendation of this conference, a committee on the subject has since been authorized by the Board of Directors and invitations are now being extended for membership on this new committee, looking toward the organization of the committee in the near future.

Other Pending Proposals.—Also proposed as subjects for Society work through the organization of new committees or reference to existing comtees are asphalt floor tile, other hard-surfaced floor coverings, wall tile, floor waxes, and graphite (especially as a lubricant). The Administrative Committee is exploring these proposals, prior to making recommendations.

QUALITY AND FORM OF STANDARDS

Reference was made in the past two reports to the efforts being made by the Administrative Committee to have the technical committees give greater attention to the quality of A.S.T.M. standards from both the editorial and technical points of view. It suggested that the subject was of sufficient importance to justify the establishment of editorial subcommittees in the individual technical committees, and this plan is being followed by a number of committees.

As a further aid to technical committees, the Technical Secretary has furnished their chairmen with copies of several helpful publications including the "Symposium on Usefulness and Limitations of Samples" presented at the last Annual Meeting, under the sponsorship of Committee E-11 on Quality Control, "Tentative Recommended Practice for Planning Interlaboratory Testing of Textile Materials (A.S.T.M. Designation: D 990 - 48 T)" prepared by Committee D-13 on Textile Materials, and a revision of the "Tentative Recommended Practices for Designating Significant Places in Specified Limiting Values (A.S.T.M. Designation: E 29 - 48 T)" appearing in the 1948 Annual Report of Committee E-11.

The Standards Committee will continue to follow the matter further with the aim of effecting still further improvement.

RELATIONS WITH AMERICAN STANDARDS ASSOCIATION

Two methods under the procedure of the American Standards Association are used by A.S.T.M. in submitting recommendations to the ASA. One is a combination of the so-called existing standards procedure and the proprietary sponsorship procedure. On the initial reference of an existing A.S.T.M. standard to the ASA, it is submitted under the existing standards procedure with a supporting statement giving a history of the development of the standard and indicating the degree of its acceptance. If the standard is approved as American Standard, the A.S.T.M. is granted proprietary sponsorship so far as any future revisions are concerned, and such revisions are currently brought to the attention of the ASA for approval under this proprietary sponsorship procedure.

The second method consists of having standards reviewed in a sectional committee made up of representatives of a number of interested organizations, but with A.S.T.M. as sponsor or co-sponsor for the sectional committee.

Standards Submitted Under the Existing Standards Procedure.—Several new standards were submitted during the past year under the existing standards procedure. These consist of a group of 8 specifications under the jurisdiction of Committee B-5 on Copper and Copper Alloys.

Revised Standards Submitted Under Proprietary Procedure.—In view of the Society having been designated as proprietary sponsor for the revisions of A.S.T.M. standards that had been approved as American Standard under the existing standards procedure, it has submitted to the American Standards Association during the year revisions of 2 specifications relating to steel, 1 relating to cast iron, 3 relating to galvanized steel fencing and wire, 1 relating to galvanized steel sheets, 1 relating to slab zinc, 1 relating to copper water tube, and 1 to copper-base forging alloys, 2 methods relating to coal and coke, 2 relating to rubber, and 3 relating to soaps.

Standards Submitted Under Sectional Committee Procedure.—During the year reports were received from three of the sectional committees for which the Society is sponsor or joint sponsor as follows:

Sectional Committee C59 on Electrical Insulating Materials.—This committee has recommended the approval of 2 revised American Standards.

Sectional Committee L14 on Textile Test Methods.—This committee has recommended the approval as American Standard of 3 methods and the approval of 1 revised American Standard.

Sectional Committee Z11 on Petroleum Products and Lubricants.—This committee has recommended for approval as American Standard 4 methods, approval of 2 revised American Standards, and the withdrawal of 1 American Standard.

All of these reports have been referred to the American Standards Association. Action is still pending so far as the recommendations of Sectional Committee Z11 are concerned; the others have been approved.

INTERNATIONAL RELATIONS

The Society continues to receive from other countries standards with the request for comment. A.S.T.M. committees review these standards and frequently suggestions result. Apart from such informal cooperation, however, quite a number of proposals have been received through the American Standards Association concerning projects that have been proposed under the International Organization for Standardization (ISO).

Textiles.—The general secretariat for ISO Committee 38 has been assigned to the British, but the United States will probably serve as the secretariat for two subcommittees. A general conference of the United States textile industry was held on September 24, 1948, at which the American delegates to the London meeting of the ISO committee (June 7–12, 1948) presented a report. The Society was represented at this meeting by A. G. Scroggie and H. J. Ball.

Petroleum Products.—The Executive Committee of Sectional Committee Z11 on Petroleum Products and Lubricants is communicating with the member bodies of that sectional committee to learn their views with respect to Sectional Committee Z11 acting as American Secretariat for this ISO committee (No. 28), including an expression of willingness or otherwise of the member bodies to support such a secretariat financially.

Rubber.—A meeting of this ISO committee (No. 45) was held in London in June, 1948, at which America was represented by Mr. H. G. Bimmerman, member of A.S.T.M. Committee D-11 on Rubber and Rubber-Like Materials. A further meeting of ISO Committee 45 is being held in September of this year, and it is understood that an invitation from the United States for the 1950 meeting of the ISO committee to be held here would be favorably received.

Viscosity.—The matter of the desirability of the United States participating in this international project was referred to Committee E-1 on Methods of Testing, which committee felt that international discussion on the subject would be desirable, provided it dealt with absolute viscosity.

Plastics.—Committee D-20 on Plastics felt that there may be some advantages resulting from an international committee on plastics in that it would provide closer liaison between the groups in this country and those in other countries.

Shellac.—Subcommittee XIII on Shellac of A.S.T.M. Committee D-1 is being set up as the American committee in charge of the contacts with the ISO Committee on Shellac (No. 50) for which India holds the secretariat.

Solid Mineral Fuels.—Committee D-5 on Coal and Coke has indicated that it favors American participation in the work of this ISO Committee No. 27.

Iron and Steel.—Committee A-1 on Steel has indicated that it favors American participation in the work of this ISO Committee No. 17.

Chemistry.—The following A.S.T.M. committees have indicated an interest in participating in the ISO Project on Chemistry:

D-1 on Paint, Varnish, Lacquer, and Related Products,
D-3 on Gaseous Fuels, and
D-12 on Soaps and Other Detergents.

Laboratory Glassware.—An ISO Project on Laboratory Glassware has been proposed with the British Standards Institution holding the secretariat. Two conferences of representatives of industry in this country have been held at which the Society was represented. These conferences have recommended that the scope of the international project be clarified and delimited before any further consideration is given to American participation.

Mica.—Committee D-9 on Electrical Insulating Materials has indicated that it favors American participation in the work of this ISO Committee No. 36.

General Definitions Relating to Chemical and Physical Tests.—The matter of American participation in the work of this ISO committee (No. 69) has been referred to Committee E-11 on Quality Control and Committee E-1 on Methods of Testing, but no recommendations have as yet been made.

Insulating Oils.—Subcommittee IV on Insulating Oils of A.S.T.M. Committee D-9 is serving in an advisory capacity to the U. S. National Committee of the International Electrotechnical Commission which functions as the Electrical Division of the ISO.

Respectfully submitted on behalf of the committee,

R. D. BONNEY,
Chairman.

R. E. HESS,
Secretary.

APPENDIX III

REPORT OF ADMINISTRATIVE COMMITTEE ON RESEARCH

The Administrative Committee on Research held one meeting during the year: at Society Headquarters on April 13, 1949.

Continuing the practice of meeting with representatives of technical committees of the Society, a report by Committee D-7 on Wood was discussed with Col. L. G. Smith, who is chairman of a D-7 task group developing a research program for more economical procedures in testing wood poles and cross arms.

Committee B-8 on Electrodeposited Metallic Coatings requested a grant to be used in support of the research activities of the American Electroplaters Society. As Committee B-8 works closely with the electroplaters in the direction of this research work and utilizes the results in its work on specifications, the committee made a grant of $250 to be allocated to Committee B-8 to support this research activity.

The committee discussed the problem of expanding the principal of the funds available to it and requested its members to continue to survey the possible sources for such support.

Research Review:

Under date of December 6, 1948, a circular letter was addressed to the chairmen of all technical committees requesting them to inform the Administrative Committee of their methods for handling research activities and to furnish a list of unsolved problems in the testing of materials in their field. The response to this request was extremely gratifying. The number of technical committees with actual machinery for processing research problems is large, although this is done by various methods. The Administrative Committee believes that this review of the emphasis on research has stimulated the technical committees as well as provided information on many important activities.

The Administrative Committee proposes to request each technical committee to select one or more of the unsolved problems in its field, giving more complete information on the scope and specific unknown elements involved in each. With this information it may be possible for the Society to publish an initial listing of research projects for the use of schools, research foundations, and industry. Such information may also disclose a mutual interest in certain areas of fundamental research. A continuation of this procedure will be of inestimable and stimulating influence on the Society's research activities.

Relations with National Research Council:

The Society is fortunate in having very close ties with the Division of Engineering and Industrial Research and with the Highway Research Board and the Building Research Advisory Board of that division of the National Research Council. Among the objectives for the Division listed by the Special Committee on Division Aims, the following are of immediate interest to our Society:

"Coordinate the engineering and

research activities of the affiliated societies in mutual fields of interest."

"Explore areas in which research is needed and elicit sponsorship from existing agencies."

These activities will be mutually beneficial to the American Society for Testing Materials and to the National Research Council.

Recommendations:

The committee feels that one of its most important duties is to stimulate research and to that end suggests that some person or group in each technical committee be assigned to keep the Society informed of all new areas of research and to point up unsolved problems of significance in our field of materials which will aid in making our coordinated research more effective. This will involve "cross-pollination" and joint meetings of two or more technical committees where problems of fundamental values are involved. Symposia of Research from time to time may become a regular part of the annual meeting.

Respectfully submitted on behalf of the committee,

WALTER C. VOSS,
Chairman.

C. L. WARWICK,
Secretary.

APPENDIX IV

REPORT OF ADMINISTRATIVE COMMITTEE ON PAPERS AND PUBLICATIONS

Two meetings of the Administrative Committee on Papers and Publications were held during the year: November 1 and February 21.

The activity of the committee has been largely one of reviewing material for publication, and in planning for its publication and in planning the technical program for the Annual Meeting. This report is accordingly largely a record of the various regular and special publications that have been issued during the past year.

A special Study Committee has been set up to review standards for A.S.T.M. papers. This committee consists of G. R. Gohn, chairman, R. C. Adams, and K. B. Woods. The committee has already established a more detailed check chart for the use of reviewers of technical papers. It is also planned to revise the Society's suggestions to authors looking toward their publication in separate pamphlet form. This brochure will probably also contain suggestions to authors with respect to presentation of technical papers.

It will be recalled that last year it was decided to increase the number of issues of the ASTM BULLETIN from six to eight issues a year. This policy is to be instituted by publishing seven issues this year, the extra issue to appear as a July number, looking toward having the full eight issues next year.

RECORD OF PUBLICATIONS ISSUED THIS YEAR

Regular Publications:

1948 Proceedings, 1366 pp, 7000 copies.

1948 Supplements to Book of Standards:
  Part I-A, 273 pp, 8400 copies.
  Part I-B, 304 pp, 7400 copies.
  Part II, 300 pp, 7000 copies.
  Part III-A 423 pp, 6750 copies.
  Part III-B 348 pp, 6500 copies.
1948 Index to A.S.T.M. Standards, 272 pp, 20,000 copies.
Year Book, 569 pp, 5800 copies.
ASTM BULLETIN, six issues, total number of pages 664, average number of copies 10,000.

A statement of the volume of the principal publications for the past four years is given below:

Publications	1945, pages	1946, pages	1947, pages	1948, pages
Proceedings	1060	1614	1206	1366
Book of A.S.T.M. Standards	....	6694	....	....
Supplements to Book of A.S.T.M. Standards	1189	....	2015	1648
A.S.T.M. Methods of Chemical Analysis of Metals	....	412	....	....
Index to A.S.T.M. Standards	235	240	254	272
Year Book	474	512	542	569
Spring Meeting Symposiums	....	166	119	....
ASTM BULLETIN	492	600	668	664
	3450	10238	4804	4519

Special Compilations of Standards Published from April 15, 1948 to April 15, 1949:

A.S.T.M. Specifications for Steel Piping Materials (A-1), 328 pp, 2400 copies.
A.S.T.M. Standards on Electrical-Heating and Resistance Alloys (B-4), 180 pp, 900 copies.
A.S.T.M. Standards on Copper and Copper Alloys (B-5), 515 pp, 1200 copies.
A.S.T.M. Standards on Light Metals and Alloys (B-7), 157 pp, 1000 copies.
A.S.T.M. Standards on Mineral Aggregates, Concrete, and Nonbituminous Highway Materials (C-9, D-4), 209 pp, 2200 copies.
A.S.T.M. Standards on Petroleum Products and Lubricants (D-2), 763 pp, 7600 copies.

A.S.T.M. Standards on Bituminous Materials for Highway Construction, Waterproofing and Roofing (D-4, D-8), 318 pp, 1500 copies.

A.S.T.M. Standards on Coal and Coke (D-5), 164 pp, 1800 copies.

A.S.T.M. Standards on Paper and Paper Products (D-6), 285 pp, 1200 copies.

A.S.T.M. Standards on Electrical Insulating Materials (D-9), 635 pp, 1500 copies.

A.S.T.M. Standards on Rubber and Rubber-Like Materials (D-11), 577 pp, 2000 copies.

A.S.T.M. Standards on Textile Materials (D-13), 559 pp, 2800 copies.

A.S.T.M. Standards on Plastics (D-20), 607 pp, 2500 copies.

Special Publications also Issued:

Symposium on Functional Tests for Ball-Bearing Greases, STP 84, 109 pp, 2500 copies.

Symposium On Mineral Aggregates, STP 83, 239 pp, 3500 copies.

Forum on Tractor Fuels, STP 82, 41 pp, 2000 copies.

Symposium on Spectroscopic Light Sources, STP 76, 81 pp, 2000 copies.

1948 Edgar Marburg Lecture—Isotopes and Their Application in the Field of Industrial Materials, P. C. Aebersold, 32 pp, 2000 copies.

In addition to the above, the Round Table Discussion on Ultrasonic Testing has been mimeographed, 500 copies.

1947 Supplement to the Bibliography and Abstracts on Electrical Contacts, 28 pp, 1200 copies.

1948 Appendix to A.S.T.M. Manual of Engine Test Methods for Rating Fuels, 20 pp, 3000 copies.

Charts from A.S.T.M. Manual of Engine Test Methods (in pads):

- Chart for Standard Thermal Plug Temperature Line, A.S.T.M. Aviation Method D 614, 10,000 copies.
- Reference Fuel Framework for Supercharge Method (D 909), 10,000 copies printed July; 10,000 copies printed October.
- Data Sheet for Supercharge Method (D 909), 10,000 copies printed July; 20,000 copies printed December.

Tables from A.S.T.M. Manual of Engine Test Methods, 500 copies.

Symposiums reprinted from 1948 Proceedings:

Symposium on Usefulness and Limitations of Samples, 40 pp, 2000 copies.

Panel Discussion on the Influence of Non-Ferrous Metals and Their Compounds on the Corrosion of Pressure Vessels, 48 pp, 2000 copies.

Symposium on Methods and Procedures Used in Identifying Reactive Materials in Concrete, 79 pp, 2000 copies.

Reprints of Publications:

Report of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete (1940), STP 5A, 145 pp, 2000 copies, Aug. 1948; 1200 with specifications,
800 without specifications,
April, 1949.

Symposium on New Methods for Particle Size Determination in the Subsieve Range (1941), STP 51, 117 pp, 750 copies.

Symposium on Analytical Colorimetry and Photometry (1944), 70 pp, 500 copies.

Symposium on Significance of Tests of Coal (1947), 126 pp, 500 copies.

Bibliography and Abstracts on Electrical Contacts (1944–1945), 48 pp, 250 copies.

Procedures for Testing Soils (1944), 214 pp, 500 copies.

A.S.T.M. Manual on Presentation of Data (third printing 1940), 82 pp, 5000 copies.

Impact Resistance and Tensile Properties of Metals at Subatmospheric Temperatures (1941), STP 47, 114 pp, 500 copies.

Hardenability Chart, 20,000 copies.

Viscosity Temperature Charts:

- Chart A, 17,000 copies
- Chart B, 43,400 copies

Radiographic Standards for Steel Castings—X-Ray Radiographic Standards—20 sets.

Significance of Tests of Petroleum Products, 80 pp, 2500 copies.

Textile Fibers—An Engineering Approach To Their Properties and Utilization by Harold DeWitt Smith—1944 Marburg Lecture, 96 pp, 2000 copies.

Special Publications in Process:

Symposium on Metallography in Color, STP 86, 72 pp, 3000 copies.

Symposium on Magnetic Testing, STP 85, 203 pp, 3000 copies.

Symposium on Deformation of Metals as Related to Forming and Service, STP 87, 120 pp, 2000 copies.

Symposium on Industrial Gear Lubricants, STP 88, 32 pp, 2000 copies.

Symposium on Effects of Low Temperature on Materials, STP 78, 100 pp, 4000 copies.

Symposium on Aging of Rubbers, STP 89, 77 pp, 4000 copies.

1948 Supplement to the Bibliography and Abstracts on Electrical Contacts, STP 56-E, 24 pp, 1200 copies.

Symposium on Speed of Testing, 90 pp, 2000 copies (reprinted from 1948 *Proceedings*)

Metal Cleaning Bibliographical Abstracts, STP 90, 100 pp, 2000 copies.

Manual on Fatigue Testing, STP 91, 100 pp, 3000 copies.

X-Ray Diffraction Data for Chemical Analysis, Second Supplement, STP 48-B 1500 cards, 2000 sets.

Tables of Data on Corrosion Resistance Steels (A-10), 32 pp, 3200 copies.

CURRENT ACTIVITIES

Program for 1949 Annual Meeting:

A very full program is in prospect for the 1949 Annual Meeting with a number of symposiums and sessions scheduled as follows:

Symposium on Accelerated Durability Testing of Bituminous Materials—under the joint auspices of Committees D-4 on Road and Paving Materials and D-8 on Bituminous Waterproofing and Roofing Materials.

Symposium on Evaluation Tests for Stainless Steels—under the auspices of Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys.

Symposium on Testing Cast Iron with SR-4 Type of Gage—under the auspices of Committee A-3 on Cast Iron.

Symposium on Methods for the Rapid Identification of Metals—under the auspices of Committee E-3 on Chemical Analysis of Metals.

Round Table Discussion on Need for Standards for Examination of Water-Borne Industrial Wastes—under the auspices of Committee D-19 on Industrial Water.

Session on Soils—under the auspices of Committee D-18 on Soils for Engineering Purposes.

Committee E-7 on Non-Destructive Testing is sponsoring two meetings at which papers on radiography and ultrasonic testing will be presented.

A discussion on Wood Pole Testing is being sponsored by Committee D-7 on Wood.

In addition to the above, there are a number of other technical papers which will be presented at the Annual Meeting. A number of papers are being offered to the Society for publication but not presentation at a meeting. These for the most part are published currently in the ASTM BULLETIN although in some cases such papers are being preprinted separately and subsequently published in the *Proceedings*.

Respectfully submitted on behalf of the committee,

C. L. WARWICK,
Chairman.

APPENDIX V

REPORT OF ADMINISTRATIVE COMMITTEE ON ULTIMATE CONSUMER GOODS

One meeting of the Administrative Committee on Ultimate Consumer Goods was held during the year, on November 30, 1948, at the headquarters of the National Federation of Textiles, New York City.

The advisory group of social scientists referred to in the last report has been organized. It has been designated as the Advisory Group on Consumer Want Determination and its personnel, composed of two natural and two social scientists, is as follows: Dr. Paul S. Olmstead, Bell Telephone Laboratories, chairman; Dr. John E. Karlin, Bell Telephone Laboratories; Dr. E. Vernon Lewis, E. I. duPont Co.; and Prof. Frederick F. Stephan, Princeton University. It has been agreed that the functions of the Advisory Group are to keep the Administrative Committee advised of present thought and techniques associated with consumer want determination, including research that is in progress or is planned; to make recommendations concerning likely directions for future research that will be of use to the Administrative Committee, including proposals as to what work should be done and where; and in respect to consumer problems in general to keep the Administrative Committee informed of relevant developments, and to act as consultants on specific problems.

The Administrative Committee has under consideration a plan to hold a symposium on test methods for consumer goods at some spring or annual meeting of the Society whenever an appropriate program of topics and papers can be arranged. It has been suggested to Committee D-13 on Textiles that a preliminary program of an educational character on this same subject might be developed for one of its meetings.

Reference was made in the last annual report of the Administrative Committee to a proposed revision of the Regulations Governing Technical Committees, which had been recommended to the Board of Directors, to provide a procedure to be followed by technical committees in developing standards for consumer goods. During the current year the original proposals were referred back to the Administrative Committee by the Board of Directors with the recommendation that clarification of certain portions was desirable. The Administrative Committee accordingly made appropriate modifications in its proposals which were then approved by the Board of Directors and, in accordance with the established procedure, submitted to the chairmen of all technical committees for advice and consultation.

The final form of the amendment is set forth in Report of the Board of Directors under Administrative Matters.

The Board of Directors will announce when these changes become effective.

The Administrative Committee recommends that R. D. Bonney and A. L. Brassell, whose terms of office on the committee expire in June, 1949, be reappointed to its membership.

Respectfully submitted on behalf of the committee,

HERBERT J. BALL,
Chairman.

R. E. HESS,
Secretary.

APPENDIX VI

REPORT OF ADMINISTRATIVE COMMITTEE ON SIMULATED SERVICE TESTING

The Administrative Committee on Simulated Service Testing held two meetings during the year which resulted in the successful conclusion of several activities and the inauguration of others.

The Symposium on Deformation of Metals as Related to Forming and Service held in conjunction with the 1948 Annual Meeting at Detroit was not only exceptionally well attended but gave ample evidence of its broad interest and application by the lively discussions which took place. After considering the papers and discussions, the committee recommended that the symposium be published by the Society as a separate publication. The Symposium is issued as *Special Technical Publication No. 87.*

As the result of group discussions with representatives of several A, B, and D group committees at the Detroit meeting, the desirability and general pattern of the proposed Symposium on Bearing Metals and Their Lubricants were ascertained. A task group, under the chairmanship of E. W. Upham, was designated to arrange for this symposium which was originally planned for the 1949 Annual Meeting. However, due to the large amount of work needed for the preparation of papers, and also the recent publication of the several year-old ASM symposium along somewhat similar lines, the committee has decided to plan this presentation for the 1950 Annual Meeting.

Recent advances in knowledge concerning the behavior of metals at "low temperatures" have been considered by the committee, and it is the concensus that the Society should be actively engaged in this field. As the initial step in this direction, the committee has approached the Joint Committee on Effect of Temperature on the Properties of Metals in order to ascertain their intent in this direction. It is proposed that definite action should be taken in this field, either by the Joint Committee or by such other group which might be established for this purpose.

While the committee has no specific recommendations to make at this time, at its early meetings it made a list of potential fields which it felt should be investigated as opportunity presented. The past work of the committee, and its current projects, are items taken from this list, which the committee keeps continually before it. Humidity is one of the subjects to which some attention has been given and this, and others, will receive further consideration at its next meeting.

Recent changes in membership appointments to the committee have had Messrs. S. A. Gordon, Glenn L. Martin Co., and Walter Ramberg, National Bureau of Standards, replacing Messrs. J. H. Frankland and D. E. Parsons, respectively, the two latter having been obliged to resign after serving the committee effectively since its organization.

The committee announces the election of Messrs. L. L. Wyman, R. E. Peterson, and C. S. Cole as Chairman, Vice-Chairman and Secretary for the period ending in 1950.

Respectfully submitted on behalf of the committee,

L. L. Wyman,
Chairman.

C. S. Cole,
Secretary.

APPENDIX VII

REPORT OF ADMINISTRATIVE COMMITTEE ON DISTRICT ACTIVITIES

One matter that has disturbed the Administrative Committee on District Activities has been the generally unsatisfactory nature of A.S.T.M. District Council Reports. Since the preparation of these reports is a burdensome task for district officers, the Administrative Committee developed a short questionnaire style report for use this year. It was felt that such a form would ease the reporting task by suggesting the details in which the Board of Directors is interested.

It is still too early to analyze the 1948 reports and establish whether they are more complete than they have been in the past and whether the district officers found the new form helpful. However, the 1948 reports have thus far come in more promptly than in former years, and the information is available in more usable form. If the form accomplishes the intended objectives, the Administrative Committee will recommend adoption of a printed form to replace this year's mimeographed temporary form.

The Administrative Committee has no new projects under consideration and, therefore, the committee has given thought to the need for its continued existence. When the committee was organized in 1945, the activities of A.S.T.M. Districts were in need of unification. The committee first undertook to revise the Charter and District Manual. These documents have been adopted and put into effect. Next, the committee studied district boundaries and recommended certain changes which have since been adopted. The need for certain new districts was recognized and these districts have been organized. A.S.T.M. Districts are now functioning in all the principal large industrial areas, where a sufficient membership concentration justifies district organizations. No further district expansion is contemplated at this time.

It has been the opinion of the Administrative Committee that A.S.T.M. Districts should operate autonomously and should make most of the decisions involving their own activities. The districts are functioning in a generally satisfactory manner, although one or two districts may be less active than the Society might desire. This is probably due to their small size, membership distribution peculiarities, or lack of aggressive leadership. Whether the Administrative Committee could and should contribute help to such districts is debatable and is a matter upon which the Board of Directors may wish to pass judgment.

Barring the assignment of new tasks by the Board of Directors, the Administrative Committee on District Activities now has no major job with which to concern itself. However, it is the opinion of some members of the committee that the committee should be maintained on a "stand-by" basis. Problems, which are not now foreseeable, may arise and could be referred to the Administrative Committee for guidance, providing the committee continues to function. The committee respectfully requests a clarification of its status, under present conditions.

Respectfully submitted on behalf of the committee,

W. H. LUTZ,
Chairman

R. J. PAINTER,
Secretary.

REPORT OF COMMITTEE A-1 ON STEEL*

Committee A-1 on Steel is completing its fiftieth year of service to the Society and to the users and producers of steel. During this half century span, many of the outstanding men in the industry have contributed their time and efforts towards the activity of the committee. The result has been 140 specifications and testing methods which are authoritative bases for the purchasing and testing of steel products.

It is of interest to note that in this, its fiftieth year, Committee A-1 has completed a new arrangement for presentation of some of its earliest specifications —those on structural steel—which were first issued in 1901. In their new form the structural specifications for specific products include only those requirements which are applicable to the particular product. For requirements generally applicable to structural steel, the individual specifications refer to a general requirement specification, which includes sections on dimensional tolerances, test specimens, testing methods, defects, marking, inspection and testing, retests and rejection. Subcommittee II on Structural Steel did a tremendous amount of work in developing the new system. Various other subcommittees of Committee A-1 as well as other committees of the Society have indicated interest in this new form for presenting specification requirements.

Personnel.—Committee A-1 has grown to include 275 voting members, consisting of 131 producers, 109 consumers, and 35 general interest members.

Subsequent to the resignation of F. H. Frankland as Chairman of Subcommittee II, C. E. Loos of the Carnegie-Illinois Steel Corp. has been appointed as chairman with Jonathan Jones of the Bethlehem Steel Co. as vice-chairman and E. J. Ruble of the Association of American Railroads as secretary. T. W. Merrill, of the Vanadium Corp. of America, has been appointed secretary of Subcommittee VI and W. Warner, Inland Steel Co., vice-chairman of Subcommittee XI.

Following the retirement and resignation of Henry Wysor from the chairmanship of Subcommittee XV, E. V. Bennett of the Bethlehem Steel Co. has been appointed as chairman with C. L. Kent of Jones & Laughlin Steel Corp. as vice-chairman. E. W. Upham of the Chrysler Corp. has resigned as chairman of the Special Subcommittee on Hardenability and has been replaced by R. B. Hooper of the same company.

Losses by Death.—The committee has lost, through death, several members, three of whom had a notable record of service in Committee A-1, Messrs. Allan W. Carpenter, Lawford H. Fry, and Jesse J. Shuman:

Allan W. Carpenter (died April 21, 1948) Engineer of Bridges for many years with the New York Central Railroad, had been affiliated with A.S.T.M. for almost forty years. He had been chairman of Committee A-1's Subcommittee on Structural Steel for a long period of time. Respected and admired by all who knew him, he did much to advance the work of the committee.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

Lawford H. Fry (died July 10, 1948), was an authority on many subjects, including design and operation of steam locomotives and the nomenclature and testing of steel. A member of the Society since 1905, he had served Committee A-1 in numerous capacities, perhaps most notably as the chairman of its Subcommittee XIII on Methods of Tests. His authoritative knowledge of nomenclature and definitions was constantly called on. He was an able counsellor in many of the administrative matters involved in the operations of Committee A-1.

Jesse J. Shuman (died October 13, 1948), had an outstanding record of service, and achievement in the Steel Committee. Affiliated since 1902 with the Society, he had participated in various phases of A.S.T.M. work. Perhaps his most notable service was as the chairman of Committee A-1's Subcommittee on Bar Steels, which he headed for almost thirty years.

In the death of these three men, Committee A-1 loses a trio of its elder statesmen who for many years had given unstintingly of their time and abilities in advancing the committee's program of standardization of specifications and test methods. Their invaluable service should be an inspiration to all members, and the committee records its appreciation of the constructive interest and the contributions of these men.

TENTATIVES AND REVISIONS OF TENTATIVES APPROVED DURING THE PAST YEAR

On November 15, 1948, the Administrative Committee on Standards approved the Tentative Specifications for Seamless and Welded Austenitic Stainless Steel Pipe (A 312 - 48 T) prepared by a joint Committee A-1 and Committee A-10 task group. The new tentative appears in the 1948 Supplement to Book of A.S.T.M. Standards, Part I-A.

A revision in the Tentative Specifications for Seamless Alloy-Steel Pipe for High-Temperature Service (A 158 - 48 T) and a tentative revision of the Standard Specifications for Carbon- and Alloy-Steel Nuts for Bolts for High-Pressure and High-Temperature Service (A 194 - 48) were given approval by the Standards Committee on December 22, 1948. On the following day, December 23, approval was given a revision in the Tentative Specifications for Alloy-Steel Bolting Material for High-Temperature Service (A 193 - 48 T). These revised tentatives appear in the 1948 Supplement to Book of A.S.T.M. Standards, Part I-A.

On January 3, 1949, the Standards Committee approved a revision in the Tentative Method of End-Quench Test for Hardenability of Steel (A 255 - 48 T) which appears in the 1948 Supplement to Book of A.S.T.M. Standards, Part I-A.

The following recommendations were given approval on May 2, 1949:

New Tentative Specifications for:

Heat Treated Carbon Steel Bars (A 321 - 49 T), and
Hot Rolled Alloy Steel Bars (A 322 - 49 T).

Revision of Tentative Specifications for:

Steel Machine Bolts and Nuts and Tap Bolts (A 307 - 49 T),
Nickel-Steel Plates for Boilers and Other Pressure Vessels (A 203 - 49 T),
Stress-Relief-Annealed Cold-Drawn Carbon-Steel Bars (A 311 - 49 T),
Chromium-Molybdenum Steel Plates for Boilers and Other Pressure Vessels (A 301 - 49 T), and
Manganese-Molybdenum Steel Plates for Boilers and Other Pressure Vessels (A 302 - 49 T).

Tentative Revision of Standard Specifications for:

High Tensile Strength Carbon-Silicon Steel Plates for Boilers and Other Pressure Vessels (A 212 - 47),
Molybdenum Steel Plates for Boilers and Other Pressure Vessels (A 204 - 47),
Manganese-Vanadium Steel Plates for Boilers and Other Pressure Vessels (A 225 - 47),
Carbon-Silicon Steel Plates of Intermediate Tensile Ranges for Fusion-Welded Boilers and Other Pressure Vessels (A 201 - 47), and
Open-Hearth Carbon Steel Rails (A 1 - 46).

Revision and Reversion to Tentative of Standard Specifications for:

Boiler and Firebox Steel for Locomotives (A 30 - 49 T), and

Low and Intermediate Tensile Strength Carbon-Steel Plates of Flange and Firebox Qualities (Plates 2 in. and under in Thickness) (A 285 – 49 T).

One week later, May 9, the Standards Committee approved the following recommendations:

New Tentative Specifications for:

General Requirements for Delivery of Rolled Steel Plates, Shapes and Bars for Structural Use (A 6 – 49 T).

Revision of Tentative Specifications for:

Low and Intermediate Tensile Strength Carbon-Steel Plates of Structural Quality (Plates 2 in. and Under in Thickness) (A 283 – 49 T), and

Intermediate Tensile Strength Carbon-Silicon Steel Plates for Machine Parts and General Construction (Plates Over 2 in. in Thickness) (A 284 – 49 T).

Revision and Reversion to Tentative of Standard Specifications for:

Steel for Bridges and Buildings (A 7 – 49 T),
Structural Silicon Steel (A 94 – 49 T),
Structural Steel for Locomotives and Cars (A 113 – 49 T),
Structural Steel for Ships (A 131 – 49 T),
Structural Rivet Steel (A 141 – 49 T),
High-Strength Structural Rivet Steel (A 195 – 49 T), and
Low-Alloy Structural Steel (A 242 – 49 T).

These ten structural specifications are being published as a group in a special pamphlet.

RECOMMENDATIONS AFFECTING STANDARDS

The committee is recommending revisions in five tentatives and four standards as itemized in the Appendix.[1] One standard is recommended to be withdrawn. Three standards are recommended to be reverted to a tentative status without change, and it is recommended that thirteen standards be reverted to tentative with revision.

These actions have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

SUBCOMMITTEE ACTIVITIES

Subcommittee I on Steel Rails and Accessories:

This subcommittee met in Pittsburgh during the week of January 24 and reviewed some changes proposed in eight specifications under its jurisdiction covering rails, joint bars, and track spikes, bolts, and nuts. Following this meeting, it recommended to Committee A-1 that Standard Specifications A 1, A 2, A 3, A 4, A 65, A 66, A 76, and A 183 be reverted to a tentative status with revision as outlined in the Appendix.

Subcommittee II on Structural Steel for Bridges, Buildings and Rolling Stock:

During the past year, Subcommittee II developed a new set-up for presentation of its specifications as explained previously in this report. Approval was given by the Administrative Committee on Standards to the revised specifications on May 9, 1949, and the specifications are being issued in a special pamphlet.

A special group in the subcommittee has under way a program for testing specimens of high strength and ordinary structural steel to determine proportional limit, yield strength, and corresponding per cent extensions under load for these values, as well as stress values for extensions of 0.3, 0.4, and 0.5 per cent. The test specimens will be prepared from flame-cut, sawed and sheared plates, and the test will also be conducted by various aging methods.

The subcommittee is recommending changes in Tentative Specification A 195 for High-Strength Structural Rivet Steel, and Specification A 113 for Structural Steel for Locomotives and Cars. These changes are outlined in the Appendix.

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[1] See p. 90.

[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

Subcommittee IV on Spring Steel and Steel Springs:

Authorization has been given to the Section on Hot Formed Springs to draft a specification for spring steel of the A.I.S.I. 8600 series. The same section now has under consideration changes in Specifications A 125 for Heat-Treated Steel Helical Springs, and Specifications A 147 for Heat-Treated Steel Elliptical Springs.

At its last meeting on January 24, Subcommittee IV gave consideration to revisions in Standard Specifications A 59, A 60, and A 68 which had been recommended by the Section on Hot Formed Springs. These proposed revisions will bring the three specifications into complete conformity with present standard manufacturing compositions and practice. The subcommittee recommends that these three specifications be revised as appended.[3]

Subcommittee V on Steel Reinforcement Bars:

At the Annual Meeting in June, 1949, Subcommittee V requested that Tentative Specifications A 305 for Minimum Requirements for the Deformations of Deformed Steel Bars for Concrete Reinforcement be revised and advanced to the status of standard. Since this action was not included in the Report of Committee A-1 as preprinted, it was necessary for the committee to receive approval of the Executive Committee of the Board of Directors. Because of the special nature of the request, approval was given subject to a unanimous affirmative letter ballot of Committee A-1.[4]

The request for this special action on Specifications A 305 came largely from the urgency of needing a standard specification ready for long-pending revisions of design codes of the American Concrete Institute and similar technical consumer groups. The work leading to the revision had been done in the laboratories and facilities of the Bureau of Standards, various universities and other research agencies, and the final results were released and approved too late for appropriate action for inclusion in the preprinted report.

Subcommittee VI on Steel Forgings and Billets:

Thirteen forging specifications under the jurisdiction of this committee were revised and submitted to A-1 letter ballot in September, 1948. While the results of the balloting were definitely affirmative, there were several negative votes, and numerous suggestions for changes were received. A small editorial group has undertaken to make the necessary changes which involve quite intensive work. The specifications in their latest form are now being once again ballotted upon by Committee A-1, and it is expected to submit these to the Administrative Committee on Standards soon after the Annual Meeting.

Subcommittee VI has been concerned with the discrepancies and misunderstandings involving the Standard Definitions of Terms Relating to Methods of Testing (E 6 – 36), and the Standard Methods of Tension Testing of Metallic Materials (E 8 – 46) as they apply to the tension testing of forgings. A special group was appointed to investigate the matter and to make a report to the subcommittee with recommendations. The group's recommendations have been received and accepted by the subcommittee. These will be passed along to Subcommittee XIII on Methods of Tests for eventual action by Committee A-1 and Committee E-1 on Methods of Testing.

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[3] These specifications were accepted as tentative by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 1.

[4] This recommendation, not preprinted, was accepted by unanimous consent, subject to unanimous affirmative letter ballot of Committee A-1, which ballot has been favorable.

The subcommittee has under preparation, a specification for alloy steel seamless drum forgings which will be a counterpart of the present specification A 266.

Subcommittee IX on Steel Tubing and Pipe:

A joint group of Subcommittee IX and Subcommittee XXII personnel still has under consideration two specifications for low-temperature application, one for pipe and one for tubing. A special group appointed to study the possible standardization of hydrostatic pressures for all types of boiler products reported it was their opinion that it was impracticable to attempt such a standardization.

Subcommittee IX has appointed representatives to serve on a special joint group with representatives from Subcommittee XXII to correlate grade numbers for the several types of steel common to the various commodities under the jurisdiction of Subcommittees IX and XXII.

Subcommittee XI on Steel for Boilers and Pressure Vessels:

The subcommittee still has under consideration a specification for $8\frac{1}{2}$ per cent nickel steel plate. There is some doubt as to whether sufficient material is furnished to this analysis to warrant an A.S.T.M. specification.

The subcommittee has written a proposed Tentative Specification for General Requirements for Delivery of Rolled Steel Plates of Flange and Firebox Qualities, and has revised three of the present boiler plate specifications in line with the new General Requirement Specification. These proposals are being balloted upon by Committee A-1. If the vote is affirmative the committee will proceed with revising the remainder of the boiler plate specifications in like manner.

The committee is recommending revisions in the marking clause of Specifications A 201, A 203, A 204, A 212, A 225, as outlined in the Appendix to this report. The committee is also recommending revisions in maximum carbon content and the tensile strength range for Tentative Specifications A 301 for Chromium-Molybdenum Steel Plates for Boilers and Other Pressure Vessels. A revision is recommended for Tentative Specifications A 300 for Steel Plates for Pressure Vessels for Service at Low Temperatures by adding a paragraph to the scope stating that steel furnished to the specification should be made by a fine grain melting practice. Revisions in Specifications A 31 for Boiler Rivet Steel and Rivets are recommended as outlined in the Appendix.

A special group has been appointed to study the yield point elongation requirements in the various plate specifications to reconcile the yield point requirement and to determine the feasibility of adopting definite minimum percentages for elongation in lieu of the present sliding scales.

Subcommittee XV on Bar Steels:

A document covering proposed mechanical testing procedures and definitions for carbon and alloy bars has been prepared and reviewed by the subcommittee. A group has been appointed to make additions to this document covering the testing of cold-drawn steel. It is anticipated that a finished document will be ready to be turned over to Subcommittee XIII very shortly.

Standard Specifications A 108 for Cold-Finished Carbon Steel Bars and Shafting is now obsolete, and a new draft has been prepared. It is expected that this revised specification will soon be ready for submittal to Committee A-1. It is also proposed to enlarge Tentative Specifications A 306 for Medium Carbon Steel Bars Subject to Mechanical Property

Requirements by the inclusion of eight grades of material. This revision will soon be submitted to Committee A-1.

The subcommittee recommends that Standard Specifications A 107 and A 108 be reverted to a tentative status.

Subcommittee XIX on Sheet Steel and Steel Sheets:

The proposed Tentative Specification for Carbon Steel Sheets and Strip of Flange and Firebox Qualities is still under consideration. The subcommittee has recommended that Standard Specifications A 109 for Cold-Rolled Steel Strip be reverted to a tentative status and revised as appended.[5] The matter of interpretation of thickness for cold-rolled strip materials was referred to a special group for study and recommendation. The same group will study the wording of the bend test clause in the present sheet specifications, particularly the matter of edge cracking and bend test specimen.

Subcommittee XXII on Valves, Fittings, Pipings and Flanges for High-Temperature and Subatmospheric Temperatures:

Still under consideration by the Section on Castings is a draft of the proposed specification consolidating the essential grades found in the present Specifications A 157 and A 217. When this proposed specification is approved, it will immediately supercede the present Specifications A 157 and A 217.

The subcommittee is recommending revisions in the physical and chemical requirements for grade F-22 in Tentative Specifications A 182 for Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service, as well as revisions in the present definitions of heat treating for austenitic steels. These revisions are outlined in the Appendix.

Subcommittee XXII is also recommending a revision in Standard Specifications A 181 for Forged or Rolled Steel Pipe Flanges for General Service, involving a change in title and scope as outlined in the Appendix.

Still under consideration by the Section on Pipe is a revision and rewriting of Specifications A 158 for Seamless Alloy-Steel Pipe for High-Temperature Service which concerns deletion of all reference to austenitic steels. This section is also concerned over the application of Tentative Specifications A 312 for High-Temperature Service. A proposed specification covering similar material, specifically for high-temperature service, has been drafted and a special group appointed to compare this proposed specification with the present Specifications A 312. Another special group in the Section on Pipe has been appointed to attempt to combine all the ferritic high temperature pipe specifications into one document.

The Low-Temperature Advisory Group has adopted a wording for a clause for general use in specifications for materials for use at low temperature.

This report has been submitted to letter ballot of the committee, which consists of 275 members; 194 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

N. L. MOCHEL,
Chairman.

H. C. LARSON,
Secretary.

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[5] These revised specifications were accepted by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 1.

APPENDIX

RECOMMENDATIONS AFFECTING STANDARDS ON STEEL

In this Appendix recommendations are given affecting certain specifications, both standard and tentative, covering various steel products. These specifications, except for A 113 and A 195, appear in their present form in either the 1946 Book of A.S.T.M. Standards, Part I-A, or the 1947 or 1948 Supplements, Part I-A, as indicated by the final number in the A.S.T.M. Designation.

REVISIONS OF TENTATIVES

Tentative Specification for Structural Steel for Locomotives and Cars (A 113 – 49 T):[1]

Table I.—Revise the bend test requirements for grade B to read as follows:

¾ in. and under	flat on itself
Over ¾ to 1 in., incl.	½
Over 1 to 1½ in., incl.	1
Over 1½ to 2 in., incl.	2
Over 2 in.	2½

Tentative Specification for Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service (A 182 – 48 T):

Table I.—Revise the chemical requirements for grade F-22 to read as follows:

Carbon, max., per cent	0.15
Manganese, per cent	0.30 to 0.60
Phosphorus, max., per cent	0.040
Sulfur, max., per cent	0.040
Silicon, max., per cent	0.50
Chromium, per cent	2.00 to 2.50
Molybdenum, per cent	0.90 to 1.10

Table II.—Revise the tension requirements for grade F-22 to read as follows:

Tensile strength, min., psi	70 000
Yield point, min. psi	40 000
Elongation in 2 in., min., per cent	20
Reduction of area, min., per cent	30

Section 5.—Revise Paragraph (*d*) to read "The austenitic steels shall receive a carbide solution treatment as described in Paragraph (*h*) except as may otherwise be agreed upon by the manufacturer and the purchaser. When specified by the purchaser, grades F 8c and F 8t shall receive a stabilizing treatment as described in Paragraph (*i*)."

Add a new Paragraph (*h*) and reletter the present Paragraph (*h*) as (*i*), revising to read as follows:

> (*h*) *Carbide Solution.*—The carbide solution treatment for austenitic steels shall consist of holding the forgings for a sufficient time at a temperature at which the chromium carbides will go into solution and then cooling in air or a liquid medium at a rate sufficient to prevent the reprecipitation.
>
> (*i*) *Stabilizing.*—The procedure for stabilizing grades F 8c and F 8t shall consist of holding the forgings at 1500 to 1600 F. for not less than 2 hr. per inch of thickness and then cooling in the furnace or in air.

Tentative Specifications for High-Strength Structural Rivet Steel (A 195 – 49 T):[1]

Section 5 (a).—For check analysis requirements, change the maximum carbon from the present "0.35" to read "0.33" per cent. In the same column, change the maximum manganese requirement from the present "1.75" to read "1.71" per cent.

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[1] Tentative Specifications A 113 – 49 T and A 195 – 49 T are issued in a special pamphlet "A.S.T.M. Specifications for Rolled Structural Steel," May, 1949.

Tentative Specifications for Nickel-Steel Plates for Boilers and Other Pressure Vessels (A 203 – 49 T):

Section 14.—Revise to read as follows:

14. (*a*) Except as specified in Paragraph (*b*), the name or brand of the manufacturer, manufacturer's test identification, class, and minimum of the range of the tensile strength specified for the grade ordered, and the letters "NI," shall be legibly stamped on each finished plate in two places not less than 12 in. from the edges and on each butt strap near the center line not less than 12 in. from each end. Plates, the maximum lengthwise and crosswise dimensions of which do not exceed 72 in., shall have the marking stamped in one place approximately midway between the center and an edge. The manufacturer's test identification number shall be legibly stamped on each test specimen.

(*b*) For plates under $\frac{1}{4}$ in. in thickness, the marking specified in Paragraphs (*a*) and (*c*) shall be legibly stenciled instead of stamped.

(*c*) Except as specified in Paragraph (*b*), when ordered for railroad service in either locomotive or stationary boilers, each plate shall be stamped with the customer's special identification serial number as indicated on order or by the customer's representative when present at the time the serial numbers are applied; in addition, the plates shall be match-marked as defined in Paragraphs (*d*), (*e*) and (*f*) so that test specimens representing them may be identified. When more than one plate is cut from an as-rolled plate, each plate shall be match-marked so that they all may be identified with the test specimen representing them.

(*d*) Each match-mark shall consist of two overlapping circles each not less than $1\frac{1}{2}$ in. in diameter, placed upon shear lines, and made by separate impressions of a single circle steel die, except as specified in Paragraph (*b*).

(*e*) Match-marked coupons, except as provided in Paragraph (*f*) shall match with the plates represented and only those which match-mark properly shall be accepted.

(*f*) When arranged with the manufacturer, for plates rolled on mills with rotary side and automatic end shears, and for plates necessitating flame cutting because of thickness or circular plates, making match-marking impracticable, the manufactuer shall furnish an affidavit, in lieu of the match-marking requirement, stating that the test coupons are representative of the plates and patterns cut from the material as indicated. If the plan of furnishing an affidavit is not satisfactory, the manufacturer and purchaser may mutually agree on some other method of test piece identification.

Tentative Specifications for Chromium-Molybdenum Steel Plates for Boilers and Other Pressure Vessels (A 301 – 49 T):

Table I.—Revise the maximum carbon requirements to read "0.21" per cent for all thicknesses of material.

Table II.—Revise the required tensile strength range from the present "70,000 to 82,000" to read "65,000 to 82,000" psi.

REVISION OF STANDARDS
IMMEDIATE ADOPTION

Standard Specifications for Silicon-Manganese Steel Bars for Springs (A 59 – 39),

Standard Specifications for Chromium-Vanadium Steel Bars for Springs (A 60 – 42),

Standard Specifications for Carbon-Steel Bars for Springs with Special Silicon Requirements (A 68 – 44):

Revision of these specifications includes revised chemical composition, requirements for check analysis, and revised dimensional tolerances. The proposed revised specifications are appended hereto.[2]

Standard Specifications for Forged or Rolled Steel Pipe Flanges for General Service (A 181 – 46):

Title.—Revise to read "Standard Specifications for Forged or Rolled Steel Pipe Flanges, Forged Fittings, and Valves and Parts for General Service."

Section 1 (*a*).—Revise to read "These specifications cover forged or rolled steel pipe flanges, forged fittings, and valves and parts for general service (Note)."

Section 4.—In Paragraphs (*a*), (*c*)

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[2] These revised specifications were accepted by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 1.

and (*e*), change the word "flange" or "flanges" to "forging" or "forgings," respectively.

Section 7.—In the second line, change "one forged or rolled flange" to read "one forging."

Section 9 (*d*).—Change the word "flange" or "flanges" to "forging" or "forgings," respectively.

Sections 11, 12 and 13.—Change the word "flange" or "flanges" to "forging" or "forgings," respectively.

REVISION OF STANDARDS AND REVERSION TO TENTATIVES

Standard Specifications for Open-Hearth Carbon-Steel Rails (A 1 – 46):

Section 1.—Revise to read as follows:

1. (*a*) These specifications cover open-hearth carbon-steel standard Tee rails of nominal weights of 61 lb. per yd. and over and are intended primarily for export and industrial use.

(*b*) Supplementary Requirements (Paragraphs S1 to S5) of an optional nature are provided. They shall apply only when specified by the purchaser.

TABLE I.—CHEMICAL REQUIREMENTS.

	Nominal Weight, lb. per yd.			
	61 to 80	81 to 90	91 to 120	121 and over
Carbon, per cent	0.55 to 0.68	0.64 to 0.77	0.67 to 0.80	0.69 to 0.82
Manganese, per cent	0.60 to 0.90	0.60 to 0.90	0.70 to 1.00	0.70 to 1.00
Phosphorus, max., per cent	0.04	0.04	0.04	0.04
Silicon, per cent	0.10 to 0.23	0.10 to 0.23	0.10 to 0.23	0.10 to 0.23

WITHDRAWAL OF STANDARD

Standard Specifications for Carbon-Steel Bars for Springs (A 14 – 44):

It is recommended that these specifications be discontinued since this material is no longer supplied, having been replaced by Standard Specifications A 68.

REVERSION OF STANDARDS TO TENTATIVES

Standard Specifications for Hot-Rolled Carbon-Steel Bars (A 107 – 47),

Standard Specifications for Cold-Finished Carbon-Steel Bars and Shafting (A 108 – 47),

Standard Specifications for Heat-Treated Carbon- and Alloy-Steel Track Bolts and Nuts (A 183 – 46):

It is recommended that these standards be reverted to tentative to facilitate revisions in the near future.

Section 7.—Revise to read as follows:

7. Separate analyses shall be made from drillings taken from test ingots representing one of the first three and one of the last three applied full ingots of the heat to determine the percentages of carbon, manganese, phosphorus, sulfur and silicon. The average analysis of the ladle test ingots shall conform to the requirements prescribed in Table I.

Table I.—Revise to read as shown in the accompanying Table I.

Section 12.—Delete, renumbering subsequent sections accordingly.

Section 13 (*b*).—Revise to read as follows, retaining the present Items (*1*) to (*4*): "When specified in accordance with Supplementary Requirement S2 a progressive all ingot nick and break test with the elimination of X-Rayls shall be performed as follows:"

Section 15.—Renumber as Section 14 and revise to read as follows:

14. (*a*) The standard length of rails shall be 39 ft. when measured at a temperature of 60 F.

(15.5 C.). Eleven per cent of the entire order will be accepted in shorter lengths varying by 1 ft. from 38 ft. to 25 ft. and a variation of 3/8 in. from the specified length will be permitted, except that on 15 per cent of the order a variation of 7/16 in. will be permitted.

(*b*) Rails 33 ft. in length may be specified in accordance with Supplementary Requirement S3. When the specified length is 33 ft., 10 per cent of the entire order will be accepted in shorter lengths varying by 1 ft. from 32 ft. to 25 ft. and a variation of 1/4 in. from the specified length will be permitted, except that on 15 per cent of the order a variation of 3/8 in. will be permitted.

Section 17.—Revise to read "Circular holes for joint bolts shall be drilled to conform to the drawings and dimensions furnished by the purchaser. A variation of 0 in. under and 1/16 in. over in the size of the bolt holes will be permitted. A variation of 1/32 in. in the location of the holes will be permitted.

Section 19.—In Item (*1*) of Paragraph (*c*), change the word "number" to read "manner."

Section 20.—In Paragraph (*a*) add a note above the example of the typical brand to read "Controlled cooled rails of sections 100 lb. nominal weight per yard and lighter (except rail section 100 RE) may be identified either by the letters "CC" in the brand or hot stamped in the web of the rail."

In Paragraph (*c*) revise the design and sizes of letters and numerals to be used in stamping to read as follows:

ABCDEFGHJK	5/8 in.
1234567890	5/8 in.

In Paragraph (*d*) change the quantity "70" to read "80" lb.

Section 21.—Renumber as Section 20 and revise to read as follows:

20. (*a*) Rails accepted as No. 2 rails shall be stamped with the figure 2 on both end faces.

(*b*) Rails accepted as X-Rayls shall be stamped with the letter "X" on both end faces.

Section 22.—Revise the classifications for loading to read as follows:

(*a*) No. 1 Rails.

(*b*) No. 2 Rails and X-Rayls.

(*c*) Short Rails.

(*d*) No subdivision by classification markings other than listed above in Paragraphs (*a*) to (*c*) is necessary for separate loading.

Section 24 (*b*).—Revise to read as follows:

(*b*) No. 2 rails will be accepted to the extent of 8 per cent of the whole order of 39-ft. standard length rails. Where rails are specified 33 ft. under Supplementary Requirement S3, 5 per cent of the whole order of 33-ft. rails will be accepted.

Section 25.—Revise Paragraphs (*a*) and (*b*) to read as follows:

25. (*a*) Controlled cooling may be specified in accordance with Supplementary Requirement S4. Rails of a nominal weight of 85 lb. per yd. and over will be controlled cooled unless otherwise specified.

(*b*) Controlled cooling may be specified for rails of a nominal weight of less than 85 lb. per yd. in accordance with Supplementary Requirement S5.

In Item (*6*) of Paragraph (*c*), revise the last sentence to read, "If for unavoidable mill conditions, this time temperature cycle is not met, the rails shall be considered controlled cooled provided the temperature at a location not less than 12 in. from the end of a rail "at approximately the center" of the middle tier does not drop below 300 F. in less than 15 hr."

Supplementary Requirements.—Add Supplementary Requirements to the specifications to read as follows:

"One or more of the following Supplementary Requirements shall apply only when specified by the purchaser in the inquiry, contract, and order.

S1. Rails of nominal weights of 50 to 60 lb. per yd. may be furnished to the requirements of these specifications for rails of 61 to 80 lb. per yd. except as provided in Section 11 (*a*).

S2. Progressive nick and break testing may be specified as prescribed in Section 12 (*b*).

S3. Rails 33 ft. in length may be specified in accordance with Section 11 (*b*).

S4. Controlled cooling may be specified for rails of nominal weight of 85 lb. per yd. and over in accordance with Section 24.

S5. Rails under 85 lb. per yd. nominal weight may be specified controlled cooled by special arrangement between the manufacturer and the purchaser.

Standard Specifications for Open-Hearth Steel Girder Rails of Plain, Grooved and Guard Types (A 2 – 27):

Section 1 (*a*).—Revise to read "Unless otherwise specified by the purchaser, girder-guard rails shall be class A."

Section 3.—Delete the present Paragraph (*b*).

Section 4.—Revise the second sentence to read "When any finished rails show piping, they shall be cut to shorter lengths until all evidence of this is removed."

Section 5.—Change the required silicon content for all classes from the present "0.15 to 0.50" to read "0.10 to 0.40" per cent.

Section 6.—Revise the second sentence to read "This analysis shall be made from drillings obtained from a test ingot taken during the pouring of the heat."

Section 7.—Add the word "ladle" before the words "test ingot."

Section 8 (*a*).—Change "four" to "three."

Section 9.—In Paragraph (*c*) delete the first sentence.

In Paragraph (*d*) change "four" to "three."

Section 11 (*c*).—Revise to read "When necessary on account of the type of track construction, and notice to that effect has been given to the manufacturer, the position of the gage line with respect to the outer edge of the base shall not vary more than $\frac{3}{64}$ in."

Section 12 (*b*).—Revise to read "The lengths shall not vary more than $\frac{1}{2}$ in. on 60 and 62 ft. rails, except that on 15 per cent of the order a variation of $\frac{5}{8}$ in. will be allowed; nor more than $\frac{1}{4}$ in. on 30 and 32 ft. rails, except that on 15 per cent of the order a variation of $\frac{3}{8}$ in. will be allowed."

Section 15.—Revise Paragraphs (*a*), (*b*), and (*c*) to read as follows:

> 15. (*a*) Rails shall be reasonably smooth on the head, reasonably straight in line and surface without any twists, waves or kinks, particular attention being given to having the ends without kinks or droop.
>
> (*b*) All burrs or flow caused by drilling or sawing shall be carefully removed.
>
> (*c*) Rails shall be free from injurious gag marks and other defects of cold straightening.

Section 16 (*a*).—In the first sentence, change "$\frac{1}{32}$" to "$\frac{1}{16}$."

Section 19 (*b*).—Revise the first sentence to read, "No. 2 rails shall be rails which by reason of surface or other imperfections are not classed as No. 1 rails, provided they do not, in the judgment of the inspector, contain imperfections in such number and of such character as to render them unfit for No. 2 rail uses, and provided they conform to the requirements specified in Section 11."

Section 20.—In Paragraph (*a*) delete the phrase "the letters "O.H."."

Revise Paragraph (*b*) to read "Both ends of all No. 2 rails shall be stamped with the figure 2 on both end faces."

Section 21 (*a*).—Revise to read "Rails shall be loaded and handled in such manner as not to bruise the flanges or cause injury."

Standard Specifications for Low-Carbon Steel Joint Bars (A 3 – 46):

Section 3.—For acid-bessemer steel change the required maximum phosphorus content from the present "0.10" to "0.11" per cent.

Section 6.—Revise the present minimum elongation in 8 in. to read "Elongation in 2 in., min., per cent . . . . 22."

Section 7.—Delete, renumbering the subsequent sections accordingly.

Section 8.—Revise to read, "Tension test specimens shall be taken from the finished rolled bars. Tension test specimens shall be of 2-in. gage length."

Section 9 (a).—Delete the reference to the bend test.

Standard Specifications for Medium-Carbon Steel Joint Bars (A 4 – 14):

Section 4.—Revise the required maximum phosphorus content from the present "0.04" to "0.05" per cent.

Standard Specifications for Boiler Rivet Steel and Rivets (A 31 – 40):

Section 3.—Revise the table of chemical compositions to read as follows:

	Grade A	Grade B
Carbon, max., per cent	...	0.27
Manganese, max., per cent	0.60	0.90
Phosphorus, max., per cent	0.04	0.04
Sulfur, max., per cent	0.05	0.05
Silicon, per cent	...	0.10 to 0.30

Section 4.—Revise to read as follows:

> 4. An analysis of each heat of steel shall be made by the manufacturer to determine the percentages of carbon, manganese, phosphorus, sulfur, and silicon. This analysis shall be made from a test ingot taken during the pouring of the heat. The chemical composition thus determined shall be reported to the purchaser or his representative, and shall conform to the requirements specified in Section 3.

Section 9 (a).—Revise to read as follows:

> 9. (*a*) Two tension, two cold-bend, and two quench-bend tests shall be made from each heat. Unless the finished material from a heat is less than 30 tons when one tension test, one cold bend test, and one quench bend test will be sufficient. Each test shall conform to the requirements specified in Sections 6 and 7.

Table I.—Delete reference to material over $1\frac{1}{2}$ to 2 in., inclusive, in specified size.

Section 11.—Revise to read "The material shall be free from injurious defects."

Section 12.—Revise to read "The rivet bars shall, when loaded for shipment, be properly separated in lifts and tagged with the name or brand of the manufacturer and the heat number for identification. The heat number shall be legibly marked on each test specimen."

Section 18.—Revise to read "The finished rivets shall be true to form and concentric and shall be free from injurious defects."

Standard Specifications for Soft Steel Track Spikes (A 65 – 33):

Section 3.—Add to the table of chemical composition requirements the following: "Copper may be specified in accordance with Supplementary Requirement S1."

Section 4 (a).—Revise the first sentence to read "A determination for carbon and copper, when copper is specified (see Supplementary Requirement S1), shall be made of each heat of steel."

Supplementary Requirement.—Add the following supplementary requirement:

> The following Supplementary Requirement shall apply only when specified by the purchaser in the inquiry, contract and order:
>
> S1. Copper may be specified under Section 3 to a minimum requirement of 0.20 per cent.

Standard Specifications for Steel Screw Spikes (A 66 – 33):

Section 1.—Reletter the present as Paragraph (*a*) and add a new Paragraph (*b*) to read "A Supplementary Requirement (Paragraph S1) of an optional nature is provided. It shall apply only when specified by the purchaser."

Section 4 (a).—Change the minimum elongation in 2 in. from the present "20" to "18" per cent.

Supplementary Requirement.—Add the following Supplementary Requirement:

> The following Supplementary Requirement shall apply only when specified by the purchaser in the inquiry, contract and order:

S1. Copper may be specified to a minimum of 0.20 per cent.

Standard Specifications for Low-Carbon Steel Track Bolts and Nuts (A 76 – 46):

Section 3 (a).—For acid-bessemer steel, change the maximum phosphorus from the present "0.10" to read "0.11" per cent.

Standard Specifications for Cold-Rolled Strip Steel (A 109 – 38):

These specifications have been extensively revised, and are appended.[2]

Standard Specifications for Carbon-Silicon Steel Plates of Intermediate Tensile Ranges for Fusion-Welded Boilers and Other Pressure Vessels (A 201 – 47):

Section 14.—Revise to read as indicated above for Section 14 in Tentative Specifications A 203, deleting the phrase "and the letters "NI"."

Standard Specifications for Molybdenum-Steel Plates for Boilers and Other Pressure Vessels (A 204 – 47):

Section 14.—Revise as indicated above for Tentative Specifications A 203, substituting the letters "MO" for the letters "NI."

Standard Specifications for High Tensile Strength Carbon-Silicon Steel Plates for Boilers and Other Pressure Vessels (Plates 6 in. and Under in Thickness) (A 212 – 47):

Section 14.—Revise as indicated above for Specifications A 201.

Standard Specifications for Manganese-Vanadium Steel Plates for Boilers and Other Pressure Vessels (A 225 – 47):

Section 14.—Revise as indicated for Section 14 in Tentative Specifications A 203 substituting the letters "MV" for the letters "NI."

Adoption of Tentative as Standard

Tentative Specifications for Minimum Requirements for the Deformations of Deformed Steel Bars for Concrete Reinforcement (A 305 – 47 T):

The recommendation that these specifications be approved for reference to letter ballot of the Society for adoption as standard with revisions appears in the Summary of Proceedings.[3]

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[3] See p. 11.

REPORT OF COMMITTEE A-3*

ON

CAST IRON

Since the 1948 Annual Meeting of the Society, the Advisory Committee and a number of the subcommittees met in Chicago, Ill., on March 1 and 2, 1949. During the year, changes in committee membership have resulted in a net increase of 3 members, the total membership of the committee now being 126, of whom 45 are classified as producers, 55 as consumers, and 26 as general interest members.

Arrangements have been made for the presentation of a Symposium on Testing Cast Iron with SR-4 Type of Gage, comprising 14 papers, on June 29, 1949, during the Annual Meeting.

Committee A-3 is also sponsoring a Symposium on the Properties, Testing, and Use of Gray Iron at the A.S.T.M. Pacific Area National Meeting in San Francisco, Calif., in October, 1949.

The Research Subcommittee has submitted a proposal to Committee A-3 that involves financing a project for research work on the elevated temperature properties of cast iron. This project is now under review in the committee.

Activities of Subcommittees include a review by Subcommittee XV of impact test methods applicable to cast iron. This review is shown in an Appendix to this report both as a matter of information and to encourage cooperative tests designed to develop a tentative specification. Subcommittee XI has prepared a questionnaire with the purpose of standardizing Brinell hardness testing of cast iron.

REVISION OF STANDARD AND REVERSION TO TENTATIVE

The committee recommends that the Standard Specifications for Automotive Gray Iron Castings (A 159 - 47)[1] be expanded to include two new alloys, designated Nos. 113 and 114 and that the specifications be reverted to tentative. The following revision is the result of considered action by representative consumers and producers in the automotive field and will bring these specifications into conformity with a projected parallel specification of the Society of Automotive Engineers:

Section 4.—Revise the title of this section to read "Physical Properties and Chemical Composition."

Change Paragraph (a) to read as follows by the addition of the italicized words: "Castings, ***except those intended for brake drums and clutch plates,*** shall conform to the requirements as to tensile strength prescribed in Table I."

Renumber the present Paragraph (b) as Paragraph (c) and add a new Paragraph (b) to read as follows: "Brake drums and clutch plates are considered as special cases under these specifications. Materials intended for such services shall conform to the requirements listed in Table II (the accompanying Table I).

Table II.—Add the accompanying Table I as a new Table II.

EDITORIAL CHANGE IN STANDARD

The committee recommends an editorial change in the Standard Specifications for Gray Iron Castings (A 48 – 48)[2] by the addition of the following new informative note: "Note 8.—A chart showing the approximate Brinell hardness-strength relationships for cast iron[3] is shown in Fig. 6" (the accompanying Fig. 1).

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] 1947 Supplement to Book of A.S.T.M. Standards, Part I-A.

TABLE I.—CHEMICAL, PHYSICAL, AND STRUCTURAL REQUIREMENTS OF AUTOMOTIVE GRAY IRON CASTINGS FOR BRAKE DRUMS AND CLUTCH PLATES.[a]

	Alloy No. 113[b, c]	Alloy No. 114[b, d]
CHEMICAL COMPOSITION		
Total Carbon, per cent	3.40 min.	3.40 min. (mandatory)
TYPICAL COMPOSITIONAL RANGES		
Silicon, per cent	1.10 to 1.70	1.10 to 1.70
Manganese, per cent	0.60 to 0.90	0.60 to 0.90
Sulfur, max., per cent	0.14	0.14
Phosphorus, max., per cent	0.20	0.20
Alloys	As required	As required
PHYSICAL PROPERTIES		
Brinell Hardness No.	179 to 229	207 to 269
Transverse Strength, min., lb.	2200	2600
Deflection, min., in.	0.20	0.27
Tensile Strength, min., psi.	30 000	40 000
STRUCTURAL PROPERTIES		
Graphite[e]	Type A, Sizes 2 to 4	Type A, Sizes 3 to 5
Matrix	Lamellar pearlite with ferrite if present not to exceed approximately 15 per cent.	Fine lamellar pearlite with excess constituent free cementite or free ferrite or both not to exceed approximately 5 per cent.

[a] Properties determined on test bar 1.2-in. in diameter, broken on 18-in. supports.

[b] These numbers are identical with corresponding S.A.E. numbers in the Standard for Automotive Gray Iron Castings of the Society of Automotive Engineers.

[c] Brake drums and clutch plates for moderate service requirements where high-carbon iron is desired and heat checking is a problem.

[d] Heavy duty drums and clutch plates where both heat checking and strength are definite requirements. Since the same base iron is indicated for both No. 113 and 114 it is presumed that alloys will be used especially in the latter to meet the strength and structural requirements.

[e] The type and size of graphite referred to in this table is in accordance with the Recommended Practice for Evaluating the Microstructure of Graphite in Gray Iron (A.S.T.M. Designation: A 247).[1]

REAFFIRMATION OF STANDARDS

The committee recommends that the following standard, which has stood for more than six years without revision, be reaffirmed and continued as such:

Standard Specifications for:

Gray Iron Castings for Valves, Flanges and Pipe Fittings (A 126 – 42).

The following three standards will be reviewed at the Annual Meeting:

Standard Specifications for:

Cast Iron Pit-Cast Pipe for Water or Other Liquids (A 44 – 41),

Cast Iron Soil Pipe and Fittings (A 74 – 42), and

Cast Iron Culvert Pipe (A 142 – 38).

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following specifications and method of test be continued as tentative for the reasons indicated:

Tentative Specifications for:

Foundry Pig Iron (A 43 – 45 T), to permit revision of silicon ranges of silvery iron and possible simplification,

Gray Iron Castings for Pressure-Containing Parts for Temperatures up to 650 F. (A 278 – 44 T), pending parallel action by the A.S.M.E. Boiler Code Committee relative to allowable stress, stress-relieving treatments and suitable marking of irons certified for use at high temperature, and

Tentative Method of:

Compression Testing of Cast Iron (A 256 – 46 T), pending reconsideration by the appropriate subcommittee.

The recommendations in this report have been submitted to letter ballot of

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[2] 1948 Supplement to Book of A.S.T.M. Standards, Part I-A.

[3] J. T. Mackenzie, "The Brinell Hardness of Gray Cast Iron and its Relation to Some Other Properties," *Proceedings*, Am. Soc Testing Mats., Vol 46, p. 1025 (1946).

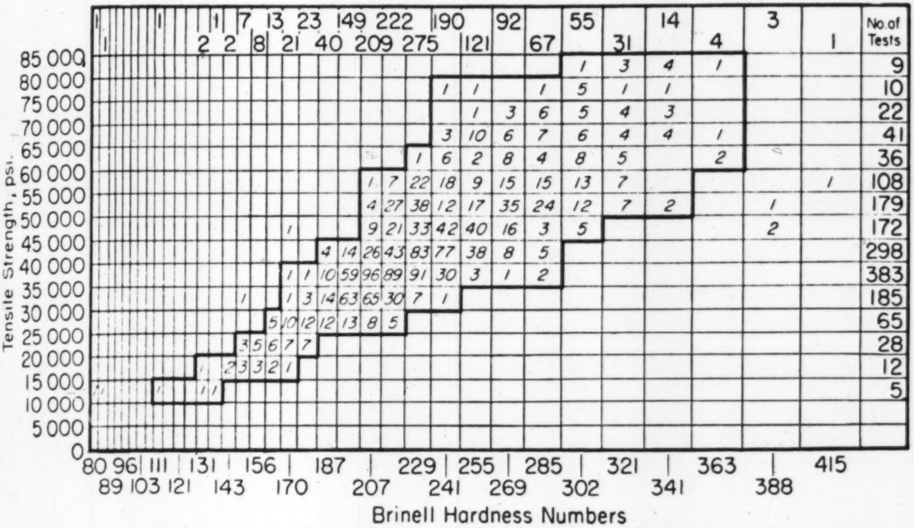

FIG. 1.—Approximate Brinell Hardness-Strength Relationship for Cast Iron.

the committee, the results of which will be reported at the Annual Meeting.[4]

This report has been submitted to letter ballot of the committee, which consists of 126 members; 81 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

E. R. YOUNG,
Chairman.

J. S. VANICK,
Vice-Chairman.

C. O. BURGESS,
Secretary.

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[4] The letter ballot vote on these recommendations was favorable: the results of the vote are on record at A.S.T.M. Headquarters.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee A-3 presented to the Society through the Administrative Committee on Standards the following recommendations:

Revision of Tentative Specifications for:

Foundry Pig Iron (A 43 - 45 T), and
Gray Iron Castings for Pressure-Containing Parts for Temperatures up to 650 F. (A 278 - 44 T).

These recommendations were accepted by the Standards Committee in December, 1949, and the revised tentative specifications appear in the 1949 Book of A.S.T.M. Standards, Part 1.

APPENDIX

REPORT OF SUBCOMMITTEE XV ON IMPACT TESTING

Subcommittee XV has continued its study of the impact testing of cast iron, the last comprehensive report of which was made to Committee A-3 in 1933.[1] The subcommittee is now presenting the attached Proposed Methods of Impact Testing of Cast Iron which include the necessary procedure for adapting the standard Charpy and Izod type of testing to cast iron, following the general principles of the Tentative Methods of Impact Testing of Metallic Materials (E 23 - 47 T).[2] Also included is a method of repeated-blow impact testing which may be performed with either a vertically dropping tup or with a pendulum type machine.

The work of the subcommittee has been concerned primarily with the adaptation of the pendulum type machine to the repeated-blow test which was first, it is believed, used by the French Ordnance Department and consists of dropping a given weight on a standard specimen from increasing heights until the specimen fails, the height of the drop being reported as the point of failure. This, of course, takes out most of the plastic component in the transverse-bending test and is quite a different test from the ordinary swing through where the specimen is broken at one blow. The latter gives the total resilience, whereas the repeated-drop test gives the resilience after most of the plastic deformation has been taken out of the specimen.

To give an example of the difference, a Ni-Resist iron, for instance, will show extremely well in the single-blow test but it shows only a mediocre value in the repeated-blow.

Figure 1 of the proposed methods shows a very simple machine.[3] It was used by Army Ordnance during the first World War. It consists of a heavy base with two 2-in. steel rods; for the 1.20-in. bar, a 25-lb. hammer is used; for the $\frac{7}{8}$-in. bar, a $12\frac{1}{2}$-lb. hammer (made of aluminum so that the relative dimensions are preserved) and for the 2-in. bar, a 50-lb. hammer is used. The important thing is that the length of this hammer be so proportioned to the distance between the guides that there be no chatter. This figure also shows the details of the 25-lb. hammer.

Figure 2 of the proposed methods shows the arrangement of supports of the type that was found best—these are of a very fine grade of steel to stand the pounding without either flattening out or chipping. The distance between supports is 4 in. for the $\frac{7}{8}$-in. bar; 6 in. for the 1.20-in. bar, and 12 in. for the 2-in. bar.

Figure 4 of the proposed methods is a detail of a spring-holding device. The bar should be ground off on the top and on both sides on a grinding wheel so the plungers will hold it in place. A spring of a certain number of coils and certain size wire holds the test specimen, pushes it down on the supports and also holds it endwise. The important point in this test is to repeat the blow at exactly the same spot.

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 33, Part I, pp. 87–129 (1933).

[2] 1947 Supplement to Book of A.S.T.M. Standards, Part I-A, p. 381.

[3] This is a slight modification of an apparatus described in the report referred to in footnote 1, *loc. cit.*, Fig. 5, p. 93.

The accompanying Fig. 1 shows a pendulum type machine adapted for repeated-blow testing. The calculation is very simple. The height of the drop is, of course, the vertical intercept of the arc. The velocity is not essentially different from that of the vertically dropping tup since the velocity in both cases is dependent upon the square root of the height. It is an easy matter to run the peg up and to keep striking the specimen which is held by a spring, shown in Fig. 3 of the proposed method.

This is a very simple little clip spring and it was found that some of the bars tended to rotate, so that this spring has been modified to make use of the shoulder device similar to the one shown for the drop test.

Comparative data for the vertical and the pendulum type of test are shown in Table I; and the accompanying Fig. 2 shows some of the broken specimens. The pendulum-broken specimens show a little cleaner pattern, that is, less shifting than with the vertical machine. Incidentally, with the vertical drop, it is very easy to hold the specimen in a gloved hand, a technique something like catching a baseball. No bodily injury has been experienced from the breaking specimen.

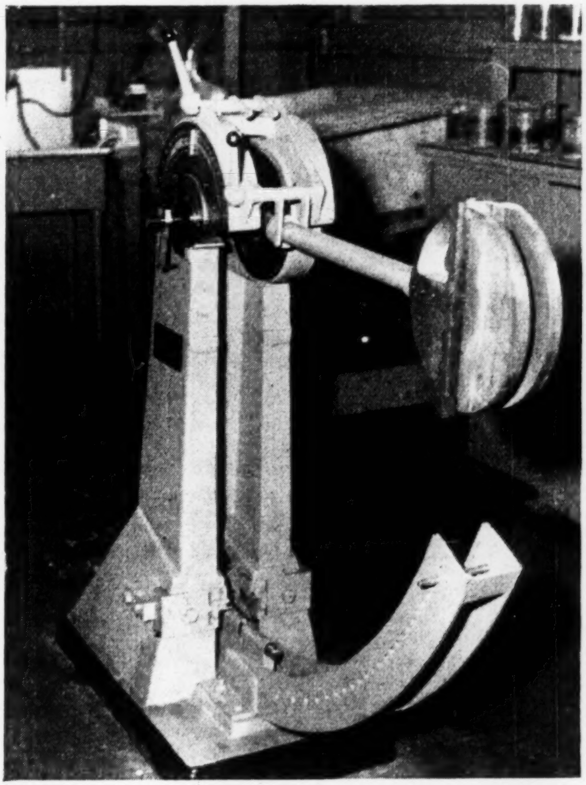

FIG. 1.—Charpy Machine Adapted for Impact Testing of Cast Iron.

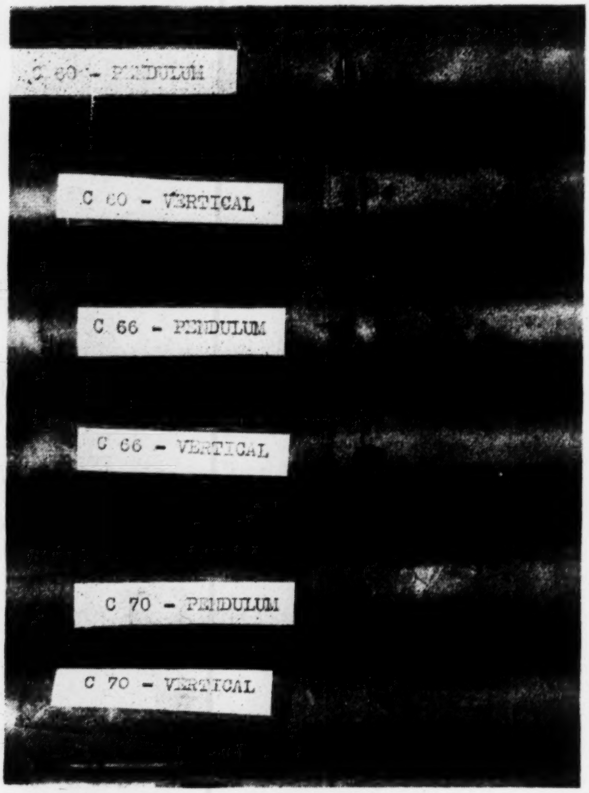

FIG. 2.—Specimens Broken in Vertical and in Pendulum Type Machines.

TABLE I.—RESULTS OF COMPARATIVE IMPACT TESTS.

Test Bar	Repeated Vertical Test		Repeated Pendulum Test	
	Diameter, in.	Height, in.	Diameter, in.	Height, in.
No. C58	1.21	12	1.22	12
No. C59	1.22	10	1.20	10
No. C61	1.19	10	1.20	9
No. C63	1.21	10	1.20	10
No. C64	1.23	11	1.21	11
No. C65	1.23	10[a]	1.20	11
No. C67	1.21	9	1.21	9
No. C69	1.21	10	1.21	11
No. C60[b]	1.12	8	1.13	10
No. C66[b]	1.12	9	1.12	8[c]
No. C70[b]	1.13	10	1.12	10

[a] Flaw in bar.
[b] Machined to 1⅛ in. diameter.
[c] Sand in bar.

NOTE.—A test on three pairs of nodular graphite bars showed an average of 34.0 in. for the pendulum and 34.5 in. for the drop.

Figure 5 of the proposed methods shows the details of the holders for the Izod test, which have been borrowed from the British Cast Iron Research Association. The feature, of course, is that these grips are set so that the specimen, in breaking, swings clear and does not bind in the grips.

The accompanying Fig. 3 shows some data furnished by the Cooper-Bessemer Corp. The impact values of the Izod test are plotted against the cube of the tensile strength divided by the square of the hardness which in the report presented in 1946[4] was found to be the best criterion of the impact value. There is one bar (marked X) that is badly out of place, but the accompanying Fig. 4 shows that this had a very peculiar structure because the tensile strength plotted

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[4] J. T. MacKenzie, "The Brinell Hardness of Gray Cast Iron and Its Relation to Some Other Properties," *Proceedings*, Am. Soc. Testing Mats., Vol. 46, p. 1025 (1946).

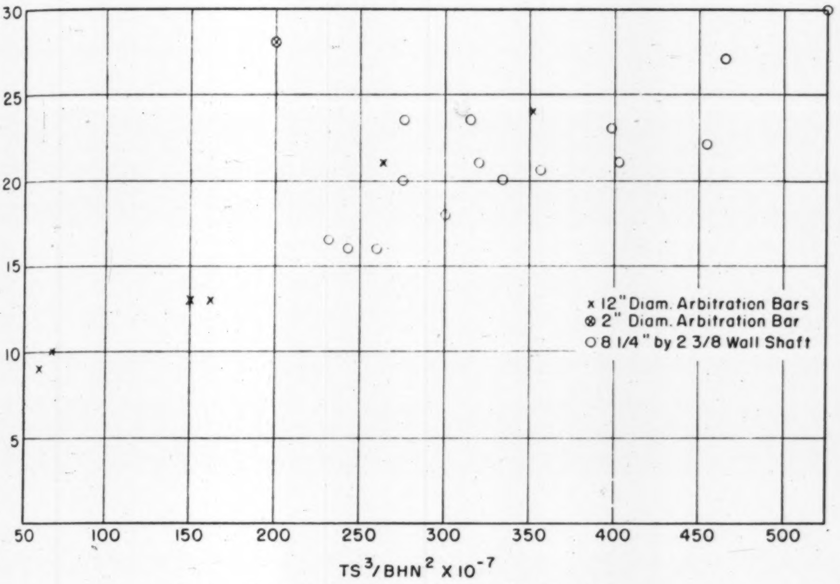

FIG. 3.—Data on Izod Impact Tests on Cast Iron.

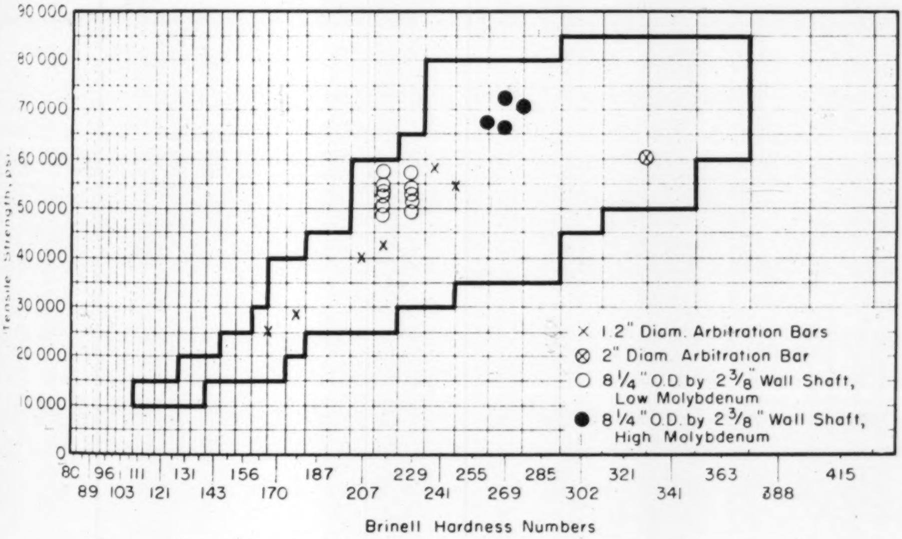

FIG. 4.—Data for Brinell Hardness - Tensile Strength Tests on Cast Iron.

against the hardness is out of line with the other specimens.

The third test is the Charpy test which uses a cylindrical specimen ground or machined down to $1\frac{1}{8}$ in. starting from a 1.20-in. bar unless otherwise stated. Comparative tests (and this is the test that has long been used by the Caterpillar Tractor Co.) on some irons that are sensitive to chilling, gave values for the machined bar as high as for the full-size as cast bar. However, on other cast irons the difference is what might be expected from the relative areas.

Respectfully submitted on behalf of the subcommittee,

J. T. MACKENZIE,
Chairman.

PROPOSED METHODS OF IMPACT TESTING OF CAST IRON[1]

These are proposed methods and are published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Scope

1. These methods of impact testing cover the details of apparatus, test specimens, and procedure for gray cast iron and include three types of test as follows:

Method A. Repeated-Blow Impact Test

Method B. Izod Type Impact Test

Method C. Charpy Type Impact Test

METHOD A. REPEATED-BLOW IMPACT TEST

Scope

2. This method covers the procedure for testing cast iron by the dropping of a hammer from increasing heights until the specimen fails.

NOTE.—The test is useful in comparing the relative toughness of cast iron under repeated impact. This test, as compared to the single blow tests of the Charpy and Izod types, which measure the total energy absorbed, measures the energy required to break the specimen *after* most of the plastic deformation has occurred.

Apparatus

3. (*a*) The test may be performed using a vertically dropping tup or with a pendulum type machine.

(*b*) A suitable apparatus, using a vertically dropping tup, is shown in Fig. 1, together with the hammer. Suitable supports for the test specimens are shown in Fig. 2. The weight of the hammer will vary in accordance with the diameter of the bar being tested as indicated in Section 5(*b*). It is important that the ratio of length of hammer to distance between guides be sufficient to prevent chatter in falling.

(*c*) The ordinary pendulum type Charpy machine may be used by clamping the specimen, as shown in Fig. 3, and releasing the pendulum from successive positions which give the equivalent inch pounds of energy corresponding to that of the falling hammer used for the apparatus with the vertically dropping tup.

Test Specimens

4. The test specimens shall have a plain cylindrical form and shall conform to the following dimensions:

Bar	Diameter, in.	Length, in.
A	0.875	5 to 7
B	1.20	7 to 9
C	2.00	13 to 15

NOTE.—These test specimens may be cut from the transverse or flexure test bars shown in Fig. 1 of the Standard Specifications for Gray Iron Castings (A.S.T.M. Designation: A 48).[2]

Procedure

5. (*a*) The bar shall be held by a suitable clamping arrangement so that successive blows always strike the same spot, but not rigid enough to affect the test. A suitable clamping device is shown

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[1] These proposed methods are under the jurisdiction of the A.S.T.M. Committee A-3 on Cast Iron. Published as information, October, 1949.

[2] 1949 Book of A.S.T.M. Standards, Part 1.

in Fig. 4 (Note), or the bar may be held by the fingers.

NOTE.—When using this type of clamping device, the bar should be ground off on top and on both sides so the plungers will hold it in place.

(*b*) The test span for the three types of bars and the weight of the hammer used shall be as follows:

Bar	Test Span, in.	Weight of Hammer lb.
A..............	4	12.5
B..............	6	25.0
C..............	12	50.0

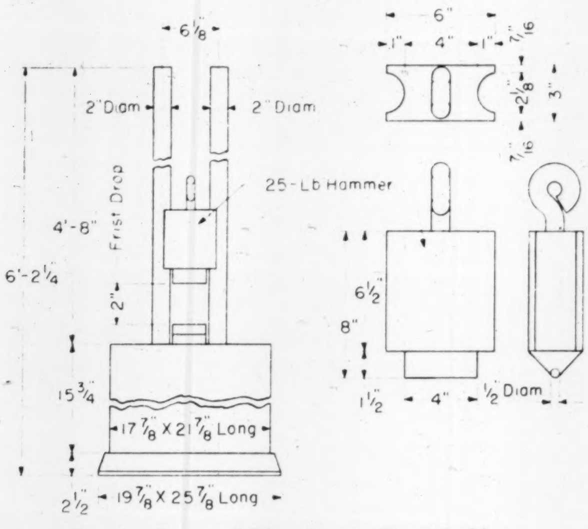


FIG. 1.—Repeated-Blow Impact Test Machine.

(*c*) The hammer shall be dropped first from a height of 2 in., next from 3 in., and so on by 1-in. increments until fracture occurs, the height of the last drop being recorded as the result of the test.

Corrections for Dimensions

6. Corrections for small deviations from standard diameter may be made on the basis of the relative areas of the cross-section of the bar tested and of the standard bar. Such corrections are of doubtful validity and bars should not be used which vary more than 5 per cent in area from the standard.

METHOD B. IZOD TYPE IMPACT TEST

Scope

7. This method of test has been developed to determine the shock resistance of gray cast iron. It is not suitable for testing austenitic or malleable cast irons.

NOTE.—The single-blow impact test on notched bar test specimens described in the Tentative Methods of Impact Testing of Metallic Materials (A.S.T.M. Designation: E 23)[2] has been found unsatisfactory for cast iron. For cast iron, the best consistency associated with a satisfactory range of results is obtained with a plain, machined, and unnotched test bar 0.798 in. in diameter (0.5 sq. in. in area).

Nomenclature

8. This test shall be known as the Izod Test for Cast Iron, and the results shall be quoted as............ft-lb. Cast Iron Izod Impact.

Apparatus

9. The single-blow Izod test for cast iron shall be carried out in a 110 or 120 ft-lb. pendulum type impact machine with a striking height of 22 mm. as used in the cantilever beam test for steel described in the Tentative Methods of Impact Testing of Metallic Materials (A.S.T.M. Designation: E 23).[2] Modifications of the grips to accommodate the larger size of test piece are shown in Fig. 5.

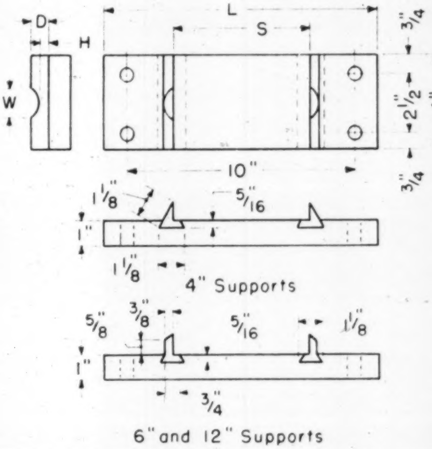
Test Specimens

10. The test specimens shall have a plain cylindrical form machined to a smooth finish, and shall conform to the following dimensions:

Diameter, in.	0.798 ± 0.002
Length, in.	3 (see Note)

Procedure

11. In all other respects, except as described above, the test shall conform to the appropriate requirements of the Tentative Methods of Impact Testing of Metallic Materials (A.S.T.M. Designation: E 23).[2]



Bar	Span, in.	*S*, in.	*W*, in.	*H*, in.	*D*, in.	*L*, in.
A	4	4	0.875	0.38	0.63	12
B	6	6	1.25	0.63	1.13	12
C	12	12	2.13	0.75	1.25	16

NOTE.—Supports to be made from S.A.E. 4815 steel, carburized and hardened.

FIG. 2.—Test Specimen Supports for Repeated-Blow Impact Test.

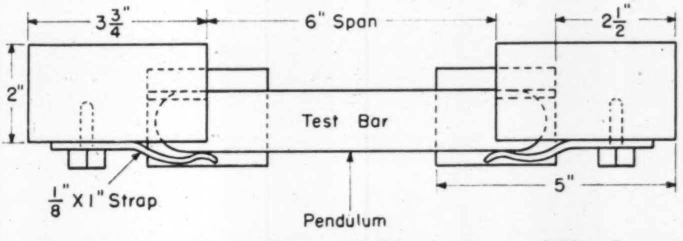


FIG. 3.—Clamp to Adapt Charpy Impact Machine for Repeated-Blow Impact Test.

NOTE.—Some machines are designed to accommodate a longer bar passing through the base into the foundations. Where such facilities exist the alternative procedure of carrying out consecutive tests on a longer bar is permissible, provided that the height of the test piece above the rear grip is maintained at 1½ in. and the fracture at the top of the bar is reasonably level, and further that the total length of the test specimen is at no time less than 3 in.

METHOD C. CHARPY TYPE IMPACT TEST

Scope

12. This test has been developed to determine the shock resistance of gray cast iron. It is not suitable for testing malleable cast irons.

NOTE.—The single-blow impact test on notched bar test specimens described in the Tentative Methods of Impact Testing of Metallic Materials (A.S.T.M. Designation: E 23)[2] has

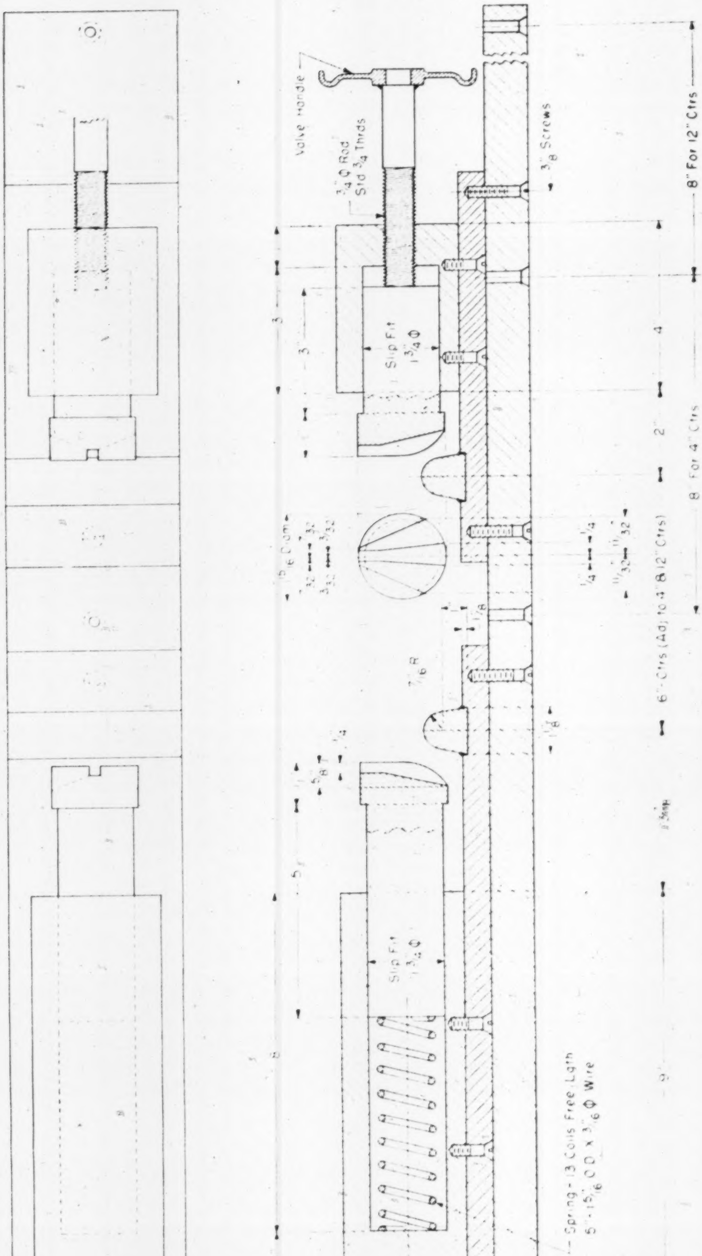
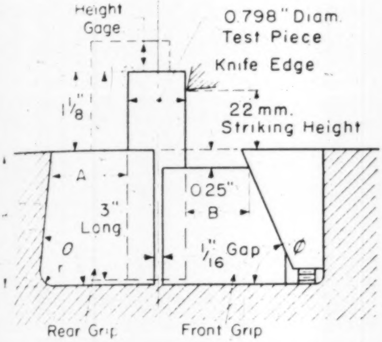

Valve Handle
3/4 Φ Rod
Std 3/4 Thds
3/8" Screws
8" For 12" Ctrs
8 For 4" Ctrs
3
3
4
2"
Slip Fit
1 3/4 Φ
1 5/16 Diam
3/32
3/32
1/4
1/4
11/32
11/32
6" Ctrs (Adj to 4" & 12" Ctrs)
7/16 R
1/8
1/8
1/4
5/8
5
8
9
Spring - 13 Coils Free Lgth
5" - 1 5/16 O.D. x 3/16 Φ Wire
2 15/16 Diam
4"
1 11/32
5/8 ℄

FIG. 4.—Clamp for Repeated-Blow Impact Test.

been found unsatisfactory for cast iron. For cast iron, the best consistency associated with a satisfactory range of results is obtained with a plain, machined, and unnotched test bar 1.125 in. in diameter (1.0 sq. in. in area).



NOTE.—Dimensions *A*, *B*, *H*, *r*, angles and ϕ, and width of grips shall be determined for each machine. The grips shall be bored so that the test specimen is in line with the center of the knife edge of the pendulum.

FIG. 5.—Modified Grips for Izod Type Impact Test.

Nomenclature

13. The test shall be known as the Charpy Impact Test for Cast Iron, and the results shall be quoted as ...... ft-lb. Cast Iron Charpy Impact.

Apparatus

14. The single-blow impact test for cast iron shall be carried out in a 110 or 120 ft-lb. pendulum type impact machine as used for the simple beam test for steel described in the Tentative Methods of Impact Testing of Metallic Materials (A.S.T.M. Designation: E 23).[2]

Test Specimens

15. The test specimens shall have a plain cylindrical form, machined or ground to a smooth finish, and shall conform to the following dimensions:

Diameter, in.	1.125 ± 0.002
Length, in.	8 ± 0.5

Procedure

16. The bars shall be tested on a 6-in. span. In all other respects the test shall conform to the appropriate requirements of the Tentative Methods of Impact Testing of Metallic Materials (A.S.T.M. Designation: E 23).[2]

REPORT OF COMMITTEE A-5
ON
CORROSION OF IRON AND STEEL*

Committee A-5 on Corrosion of Iron and Steel held two meetings during the past year: on June 23, 1948, in Detroit, Mich., during the Annual Meeting of the Society, and on February 28, 1949, in Chicago, Ill., during the Spring Group Committee Meetings.

Since the last report, the additions to the membership and the resignations and deaths were equal. The total membership of the committee is now 130, of whom 58 are classified as producers, 42 as consumers, and 30 as general interest members.

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the Tentative Method of Test for Weight and Composition of Coating on Long Terne Sheets by the Triple Spot Test (A 309 - 47 T)[1] be approved for reference to letter ballot of the Society for adoption as standard without revision.

The committee also recommends that the Tentative Specifications for Zinc Coating (Hot Dip) on Iron and Steel Hardware (A 153 - 47 T)[1] be approved for reference to letter ballot of the Society for adoption as standard with the following revisions:

Section 8.—Change to read as follows:

> 8. Necessary precautions properly to fabricate and prepare the material for galvanizing to prevent embrittlement are described in the Recommended Practice for Safeguarding Against Embrittlement of Hot Galvanized Structural Steel Products and Procedure for Detecting Embrittlement (A.S.T.M. Designation: A 143). Material found to be embrittled shall be rejected.

Section 10.—Add the following sentence to the end of this section: "Threads in nuts may be tapped after galvanizing."

The change in Section 8 will make this paragraph agree with the "embrittlement clause" in other A.S.T.M. Specifications so that the wording may be considered standard. Section 10, as now written, does not make it clear that it is permissible to tap nuts after galvanizing. The addition of the proposed sentence will clarify this point.

REAFFIRMATION OF STANDARDS

The committee recommends the reaffirmation of the following six standards[2] without change because they are still in conformity with present-day manufacturing practices.

Standard Specifications for:

Zinc-Coated (Galvanized) Iron or Steel Telephone and Telegraph Line Wire (A 111 - 43),
Zinc-Coated (Galvanized) Iron or Steel Tie Wires (A 112 - 33),
Zinc-Coated Iron or Steel Chain-Link Fence Fabric Galvanized After Weaving (A 117 - 33),
Zinc-Coated Steel Wire Strand ("Galvanized" and Class A ("Extra Galvanized")) (A 122 - 41), and
Zinc-Coated Steel Wire Strand (Class B and Class C Coatings) (A 218 - 41).

Standard Method of Test for:

Weight of Coating on Zinc-Coated (Galvanized) Iron or Steel Articles (A 90 - 39).

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] 1947 Supplement to Book of A.S.T.M. Standards, Part I-A.

[2] 1946 Book of A.S.T.M. Standards, Part I-A.

Tentatives Continued Without Revision

The committee recommends the continuance of the following tentatives without change:

Tentative Methods of Test for Local Thickness of Electrodeposited Coatings (**A 219 - 45 T**).[2]—These methods are under the joint jurisdiction of Committee A-5 and Committee B-8 on Electrodeposited Metallic Coatings which both recommend that these methods remain tentative. Committee B-8 has investigations under way pertaining to these methods and it is believed desirable to retain the tentative status until the investigations have been completed.

Tentative Specifications for Lead-Alloy Coating (Hot-Dip) on Iron or Steel Hardware (**A 267 - 46 T**).[2]—It is anticipated that a lead coating with a much higher tin content will soon be proposed for incorporation in the specifications. It is desirable to make this change before the specifications are advanced to standard.

Tentative Specifications for Long-Terne Iron or Steel Sheets (**A 308 - 47 T**).[1]—These specifications will probably be amended in the near future to include sheets coated in coils.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

Activities of Subcommittees

Subcommittee VII on Methods of Testing (W. E. Buck, chairman) is studying a method of determining the weight of zinc coatings, using 1:1 hydrochloric acid instead of concentrated acid as in the present hydrochloric acid-antimony chloride method of Standard Methods of Test for Weight of Coating on Zinc-Coated (Galvanized) Iron or Steel Articles (A 90 - 39). The results thus far have been very encouraging, and it is hoped an alternate method for determining the weight of coating can soon be recommended. The subcommittee is also investigating an alternate to the present concentrated sulfuric acid method for determining the weight of coating on terne plate and tin plate as given in Tentative Method A 309. The method under investigation will remove the hazard to the analyst which exists because of the use of concentrated sulfuric acid. This subcommittee will develop, if possible, field conformance tests as alternates for lengthy, time-consuming, laboratory tests. This subcommittee also recommended the change in the "end point" definition in Standard Method A 239 given earlier in this report.

Subcommittee XI on Sheet Specifications (E. F. Lundeen, chairman) has under consideration increasing the scope of Tentative Specifications for Zinc-Coated (Galvanized) Iron or Steel Sheets (A 93 - 48 T) and the Tentative Specifications for Long-Terne Sheets (A 308 - 47 T) to include sheets coated in coils.

Subcommittee XII on Wire Specifications (P. C. Chisler, chairman) is working on revisions of Standard Specifications for Zinc-Coated (Galvanized) Iron or Steel Telephone and Telegraph Line Wire (A 111 - 43), Zinc-Coated (Galvanized) Iron or Steel Tie Wires (A 112 - 33), Zinc-Coated, (Galvanized) Iron or Steel Farm-Field and Railroad Right-of-Way Wire Fencing (A 116 - 48), and Zinc-Coated (Galvanized) Iron or Steel Barbed Wire (A 121 - 48).

The change in Specifications A 111 will consist mainly in revising the tables. Specifications A 112 are being reviewed and will be brought up to date. In so far as Specifications A 116 are concerned, it is intended to write product specifications, that is, to split it into two specifications, one for farm-field fence and the other for railroad right-of-way fence. It has not yet been decided whether each of the two resulting product specifications, for farm-field fence and railroad right-of-way fence plus Specifications A 121 for barbed wire should each be split further into a specification with the readily available commercial weights of coating and a specification with heavy coatings.

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[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

Consideration is being given to adopting a uniform definition of the word "strand" in the various specifications which are under the jurisdiction of this committee.

Subcommittee XIII on Hardware Specifications (B. J. Barmack, chairman) recommended the rewording of Sections 8 and 10 of Specifications A 153, referred to earlier in this report and their adoption as standard. Specifications A 153 will be studied as to the need for including low-alloy steel base material galvanized after fabrication.

Subcommittee XIV on Sheet Tests (E. S. Taylerson, chairman) continued its field inspections of sheets in accordance with the regular schedule. No report has been made this year because the additional failures have been so few in number.

Subcommittee XV on Wire Tests (A. P. Jahn, chairman).—The report of this subcommittee is appended hereto under the title "Subcommittee XV on Field Tests of Wire and Wire Products."

Subcommittee XVI on Hardware Tests.—Mr. L. J. Waldron found it necessary to submit his resignation as chairman of this subcommittee. Mr. Waldron's resignation was accepted with regret and with the appreciation of Committee A-5 for the work he has done as chairman. Consideration has been given recently to extending the hardware tests. No conclusions have been arrived at as to the need for the tests so that the matter is being held in abeyance.

RESEARCH ACTIVITIES

The research activities of Committee A-5 are conducted by Subcommittees VII, XIII, XIV, XV, and XVI with the Advisory Subcommittee functioning to coordinate the work. As mentioned earlier in this report, Subcommittee VII is studying a method of determining the weight of zinc coatings in which a 1:1 hydrochloric acid is used instead of concentrated acid. This subcommittee is also investigating an alternate for the present concentrated sulfuric acid method of determining the weight of coating on terne plate and tin plate. It plans to undertake to develop field conformance tests as alternates for lengthy, time-consuming laboratory tests. Subcommittee XIII has been gathering data on weights of coatings for steel hardware; it is also gathering data on weights of coatings for malleable castings and is investigating the use of base materials for hardware, such as low-alloy high-strength steel. Subcommittee XIII is investigating the variations in weights of coatings on steel hardware and malleable castings caused by different galvanized processes and the shapes and sizes of the articles. It is also investigating the use of various base materials for hardware such as low-alloy, high-strength steel. The work of Subcommittee XIII and the resulting specifications are based on research, investigations, and data compiled by its various members for the benefit of the whole committee.

Subcommittees XIV, XV, and XVI have no new research programs under way but are continuing to appraise the efficiency of various types and weights of protective coatings on sheets, wire, and hardware.

This report has been submitted to letter ballot of the committee, which consists of 130 members; 70 members returned their ballots, of whom 42 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

T. R. GALLOWAY,
Chairman.

H. F. HORMANN,
Secretary.

REPORT OF SUBCOMMITTEE XV ON FIELD TESTS OF WIRE AND WIRE PRODUCTS

(COVERS 1948 INSPECTIONS)

This report summarizes the results of the atmospheric corrosion tests on wire and wire products through 1948. Detailed results are reported in the odd-numbered years, and reference to these earlier reports of Committee A-5 on Corrosion of Iron and Steel, which appeared in the Society's *Proceedings* for 1939, 1941, 1943, 1945, and 1947, will be helpful in studies of these exposure test results. These earlier reports contain descriptions of the test methods and micrographs and other characterizations of specimens in the test as well as the data assembled during previous inspections.

The materials under test are mostly bare steel and zinc-coated wires and wire products but copper-covered and lead-coated steel wires and chromium and chromium-nickel steel wires are also included. The coatings are expressed in weight in terms of ounces per square foot of surface. For ready comparisons of coating thickness, 1 oz. per sq. ft. of surface may be considered as averaging 0.0017 in. thick for zinc coatings, 0.0010 in. thick for lead[1] coatings and 0.0013 in. thick for copper coatings. Specimens of wires and wire products have been exposed for about twelve years at eleven locations. These locations have severely industrial, industrial, rural, or seacoast atmospheres. The location of these sites and their general classification regarding atmospheres are as follows:

Test Location	General Type of Atmosphere	Remarks
Pittsburgh, Pa.	Severe industrial	On Brunot Island in the Ohio River about 2 miles west of the city.
Bridgeport, Conn.	Industrial	In the city.
Sandy Hook, N. J.	Seacoast	About 300 yd. from Atlantic Ocean.
Santa Cruz, Calif.	Seacoast	About 3 miles from Pacific Ocean.
State College, Pa.	Rural	Central Pennsylvania.
Lafayette, Ind.	Rural	Wabash River Valley.
Ames, Iowa	Rural	Central Iowa.
Manhattan, Kans.	Rural	Kansas River Valley.
Ithaca, N. Y.	Rural	Central New York.
College Station, Tex.	Rural	About 120 miles inland.
Davis, Calif.	Rural	About 80 miles inland.

At each location, more than 900 specimens were exposed. These included short lengths of wire (42 in. long) and wire strand at all locations; farm field fence at nine sites; barbed wire at eight locations; and chain link fence at eight locations.

The extent of corrosion is being measured by visual examination of all specimens at the test site and by tension tests on the unfabricated wire specimens. Loss of weight tests on lengths of zinc-coated wire were completed earlier in this corrosion study and the results were reported in the above-mentioned *Proceedings*. During 1947 and 1948 the Pittsburgh specimens were inspected in the spring; and Bridgeport, Sandy Hook, and State College specimens were inspected in the spring and fall of each year by a traveling committee. Inspections were made in the fall of 1947 and fall

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[1] The lead-coated wires in these tests were lead coated over a bonding coat of zinc. See *Proceedings*, Am. Soc Testing Mats., Vol. 43, p. 87 (1943).

TABLE A.—CORROSION CONDITIONS OF ZINC-COATED UNFABRICATED WIRES AFTER APPROXIMATELY 12 YEARS' EXPOSURE.

R = rust; Y = yellowed; G = gray; M = metallic; MG and GY = intermediate states; D = dark to exclusion of better observation; SR and SY = superficial R and Y; R+Y = indistinguishable proportions of R and Y; Gn = green; Br = brown; PHR and PHY = rust or yellowed in pin holes.

Location	Coating Group, oz. per sq. ft. of surface										
	0.20 to 0.30	0.25 to 0.35	0.35 to 0.45	0.45 to 0.55	0.50 to 0.60	0.60 to 0.70	0.70 to 0.85	0.80 to 1.00	1.20 to 1.35	1.60 to 1.85	2.00 or more
Pittsburgh, Pa	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R
Sandy Hook, N. J.	100R	100R	100R	100R	100R	100R	100R	100R	95R	5R	G
Bridgeport, Conn.	100R	100R	100R	100R	100R	100R	100R	100R	97R	10R	GY
State College, Pa.	100R	100R	100R	100R	75R	60R	35R	5R	GY	G	G
Lafayette, Ind.	100R	100R	100R	100R	100R	90R	75R	50R	GY	G	G
Ames, Iowa	100R	95R	95R	15R	5R	2R	1R	G	G	G	G
Manhattan, Kans.	35R	35R	5R	2R	1R	G	G	G	MG	MG	MG
Ithaca, N. Y.	100R	100R	100R	99R	99R	60R	35R	3R	GY	MG	MG
Santa Cruz, Calif.	1R	10R	GY	GY	G	G	G	G	....	MG	MG
College Sta., Tex.	55R	40R	3R	3R	1R	2R	1R	1R	G	G	G
Davis, Calif.	10R	5R	G	G	G	G	G	G	....	MG	MG

TABLE B.—CORROSION CONDITIONS OF UNFABRICATED WIRES CARRYING COATINGS OTHER THAN ZINC AFTER APPROXIMATELY 12 YEARS' EXPOSURE.

R = rust; Y = yellowed; G = gray; M = metallic; MG and GY = intermediate states; D = dark to exclusion of better observation; SR and SY = superficial R and Y; R+Y = indistinguishable proportions of R and Y; Gn = green Br = brown; PHR and PHY = rust or yellowed in pin holes.

Location	Coating Groups and Corrosion Resistant Groups				
	Copper-Covered Wires[a]	Lead-Coated Wires[b]	12-14% Chromium Cold Drawn	12-14% Chromium Air Quenched	18% Chromium 8% Nickel
Pittsburgh, Pa.	D	D	D	D	D
Sandy Hook, N. J.	Gn	100R+Y	YSR	YSR	GY
Bridgeport, Conn.	Gn	R	GY	GY	MG
State College, Pa.	Gn	100R+Y	MG	MG	M
Lafayette, Ind.	Gn	80PHR	M	M	M
Ames, Iowa	Br	25R	SY	SY	SY
Manhattan, Kans.	Br	5R	MG	MG	M
Ithaca, N. Y.	B	5R	SY	SY	M
Santa Cruz, Calif.	Br	30SR	65SR	25SR	MG
College Sta., Tex.	Br	20R+Y	99R+Y	80R+Y	M
Davis, Calif.	Br	35SR	45SR	20SR	MG

[a] Weight of coating, 7 to 9 oz. per sq. ft. of surface.
[b] Weight of coating, 1.4 to 1.9 oz. per sq. ft. of surface.

TABLE C.—CORROSION CONDITIONS OF FARM FIELD FENCE AFTER APPROXIMATELY 12 YEARS' EXPOSURE.

R = rust; Y = yellowed; R+Y = indistinguishable proportions of R and Y; G = gray; M = metallic; MG and GY = intermediate state; PHR, PHY = pin hole rusting or yellowing; SR, SY = superficial rust or yellowing; Gn = green; Br = brown.

Location	Coating Group, oz. zinc per sq. ft. of surface							Copper-Covered[a]	Lead-Coated[b]	Chromium-Nickel Steel
	0.20 to 0.30	0.25 to 0.35	0.35 to 0.45	0.45 to 0.55	0.50 to 0.60	0.60 to 0.70	0.70 or more			
State College, Pa.	100R	100R	100R	100R	60R	40R	2R	Gn	100R+Y	MG
Lafayette, Ind.	100R	100R	100R	100R	90R	65R	5R	Gn	50PHR	M
Ames, Iowa	100R	100R	50R	10R	10R	G	G	Br	25R	SY
Manhattan, Kans.	15R	20R	GY	GY	G	G	MG	Br	10R	MG
Ithaca, N. Y.	100R	99R	90R	75R	50R	25R	2R	Gn	10R	MG
Santa Cruz, Calif.	5R	15R	GY	GY	G	G	MG	Br	40SR	50R
College Sta., Tex.	50R	30R	10R	5R	2R	2R	G	Br	10R	SR
Davis, Calif.	10R	3R	G	G	G	G	MG	Br	50SR	10SR

[a] Weight of coatings, 3.97 oz. per sq. ft. of surface.
[b] Weight of coating, 1.83 oz. per sq. ft. of surface.

TABLE D.—CORROSION CONDITIONS OF BARBED WIRE AFTER APPROXIMATELY 12 YEARS' EXPOSURE.

R = rust; Y = yellowed; R+Y = indistinguishable proportions of R and Y; G = gray; M = metallic; MG and GY = intermediate state; PHR, PHY = pin hole rusting or yellowing; SR, SY = superficial rust or yellowing; Gn = green; Br = brown.

Location	Coating Group, oz. zinc per sq. ft. of surface							Copper-Covered[a]	Lead-Coated[b]
	0.20 to 0.30	0.35 to 0.45	0.50 to 0.60	0.70 to 0.85	0.80 to 1.00	1.60 to 1.80	2.00 or more		
State College, Pa.	100R	100R	60R	G	GY	G	G	Gn	....
Lafayette, Ind.	100R	100R	99R	30R	5R	GY	GY	Gn	50PHR
Ames, Iowa	100R	70R	3R	G	G	G	G	Br	10R
Manhattan, Kans.	20R	GY	GY	MG	MG	MG	MG	Br	5R
Ithaca, N. Y.	100R	95R	35R	1R	G	G	M	Gn	10R
Santa Cruz, Calif.	GY	GY	GY	MG	G	G	MG	Br	25SR
College Sta., Tex.	55R	5R	2R	G	G	G	G	Br	3R
Davis, Calif.	3R	G	G	MG	MG	MG	MG	Br	25SR

[a] Weight of coating, 3.97 oz. per sq. ft. of surface.
[b] Weight of coating, 1.83 oz. per sq. ft. of surface.

TABLE E.—CORROSION CONDITIONS OF CHAIN LINK FENCE AFTER APPROXIMATELY 12 YEARS' EXPOSURE.

R = rust; Y = yellowed; R+Y = indistinguishable proportions of R and Y; G = gray; M = metallic; MG and GY= intermediate state; PHR, PHY = pin hole rusting or yellowing; SR, SY = superficial rust or yellowing; Gn = green; Br = brown; D = dark (dirt or soot) to the exclusion of a better observation.

Location	Coating Group, oz. zinc per sq. ft. of surface					Copper Covered[c]	Lead-Coated[d]	Corrosion Resistant
	0.29 to 0.52[a]	1.13 to 1.22[a]	2.09 to 2.92[a]	1.40 to 1.97[b]	4.21 or more[b]			
Pittsburgh, Pa.	100R	100R	100R	100R	100R	..	50R	D
Sandy Hook, N. J.	100R	100R	G	70R	GY	Gn	60R+Y	M
Bridgeport, Conn.	100R	95R	G	60R	GY	Gn	Y	MG
State College, Pa.	90R	GY	G	GY	G	Gn	100R+Y	M
Lafayette, Ind.	100R	G	MG	1R	GY	Gn	50PHR	M
Ithaca, N. Y.	95R	G	MG	G	G	Br	5R	M
Santa Cruz, Calif.	GY	MG	MG	MG	MG	Br	25SR	MG
Davis, Calif.	3R	MG	MG	MG	MG	Br	35SR	MG

[a] Coated before weaving.
[b] Coated after weaving.
[c] Weight of coating, 8.52 oz. per sq. ft. of surface.
[d] Weight of coating, 1.75 oz. per sq. ft. of surface.

TABLE F.—CORROSION CONDITIONS OF WIRE STRAND AFTER APPROXIMATELY 12 YEARS' EXPOSURE.

R = rust; Y = yellowed; R+Y = indistinguishable proportions of R and Y; G = gray; M = metallic; MG and GY = intermediate state; PHR, PHY = pin hole rusting or yellowing; SR, SY = superficial rust or yellowing; Gn = green; Br = brown; D = dark (dirt or soot) to the exclusion of a better observation.

Location	Coating Group, oz. zinc per sq. ft. of surface				Lead-Coated[a]
	0.69 to 0.93	1.03 to 1.17	1.32 to 1.51	1.71 to 2.47	
Pittsburgh, Pa.	100R	100R	100R	80R	100R+Y
Sandy Hook, N. J.	25R	5R	2Y	G	100R+Y
Bridgeport, Conn.	35R	5R	GY	GY	5R
State College, Pa.	G	G	G	G	95R+Y
Lafayette, Ind.	G	G	G	G	35PHR
Ames, Iowa	G	G	G	G	25R
Manhattan, Kans.	MG	MG	MG	MG	20PHY
Ithaca, N. Y.	G	G	G	M	10R
Santa Cruz, Calif.	G	G	G	MG	55SR
College Sta., Tex.	G	G	G	G	5R
Davis, Calif.	G	MG	MG	MG	55SR

[a] Weight of coating, 1.96 oz. per sq. ft. of surface.

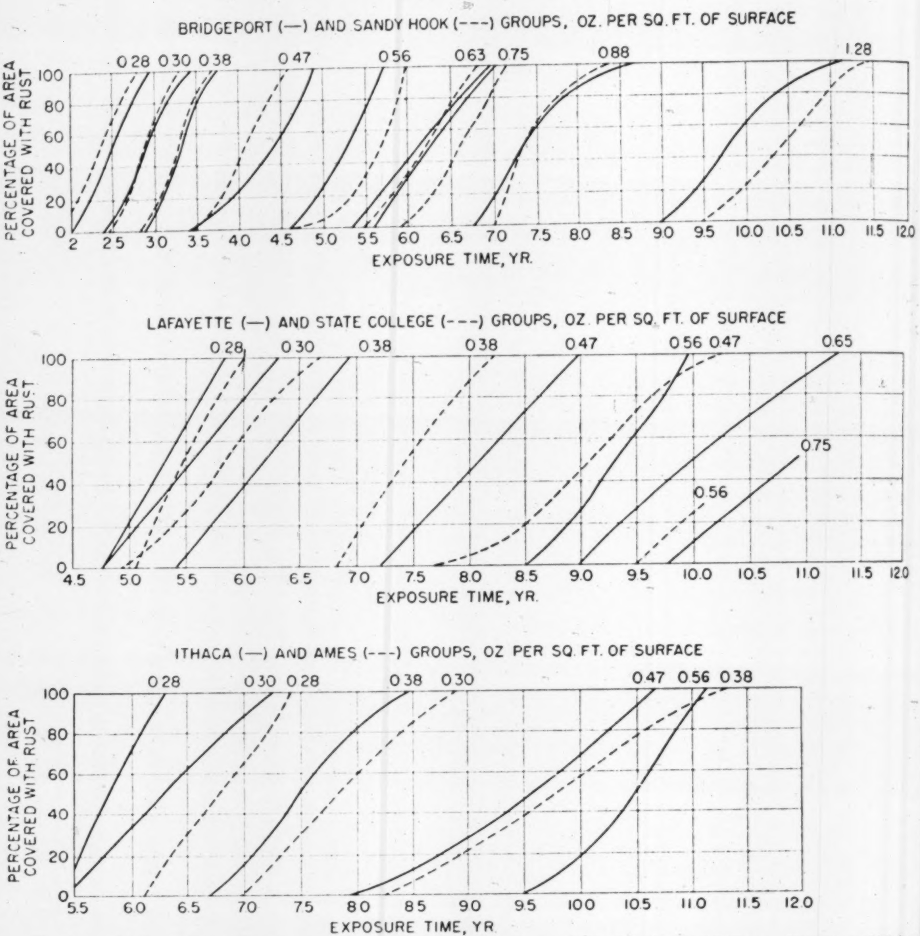

Fig. 1.—Progressive Development of Rust on Zinc-Coated Unfabricated Wire. Coating-Weight Groups in which all the samples are rusted.

Exposure time is the average time for samples of any group to rust to the extent indicated.

of 1948 at the other test sites by the university representative in charge of the test plots, namely:

I. D. Mayer	Lafayette, Ind.
Henry Giese	Ames, Iowa
F. C. Fenton	Manhattan, Kans.
B. A. Jennings	Ithaca, N. Y.
H. P. Smith	College Station, Tex.
L. W. Neubauer	Davis and Santa Cruz, Calif.

Tension test specimens were removed from all test sites during the 1947 and 1948 period and tension tests were made on these selected specimens.

Findings from Visual Examination for Corrosion at the Test Plots:

At the time of inspection, records are made of the appearance of each specimen. Prior to the time of rusting the specimens are noted as appearing "metallic," "gray," "yellow," etc. After rusting has begun, estimates are made of the percentage of area rusted on each specimen.

The condensed and summarized inspection records of corrosion through 1948 are shown in Tables A and B for unfabricated wire specimens, Table C for farm field fence, Table D for barbed wire, Table E for chain link fence, and Table F for wire strand.

In Fig. 1 is shown the progressive development of rust on zinc-coated, unfabricated wire specimens for all groups which have become 100 per cent rusted and for all groups of wire, which while not 100 per cent rusted, show some rust on each specimen of the group. In this Fig. 1 are included groups from Sandy Hook, Bridgeport, Lafayette, State College, Ithaca, and Ames sites. The data from all groups at the Pittsburgh site were reported in 1947.[2] Specimens at other locations have not yet rusted to the extent that the development of rust can be shown graphically for these sites.

The detailed inspection records collected in 1947 and 1948 are presented at the end of this report in Table I for unfabricated wire, Table II for barbed wire, Table III for farm field fence, Table IV for chain link fence, and Table V for wire strand. These tables are similar in form to the tables in previous reports. Detailed records for the Pittsburgh, Pa., site are not included in the tables because, in general, everything exposed at Pittsburgh has already been reported as 100 per cent rusted, or is so covered with soot that a good observation is not possible.

The corrosion performance of any individual specimen of barbed wire or of farm field fence listed in Tables II and III may be directly compared with the performance of specific unfabricated wire specimens listed in Table I. The Reference Information Table in this respect shows the lot numbers of wires used in fabricating all farm field fence and barbed wire samples.

Findings from Specimens Removed for Tension Tests:

Tension tests are made on the unfabricated wire specimens which were exposed in groups of seven comparison samples taken from the same lot of wire and supposedly alike. An attempt is made to remove and test the first specimen of each group when it has lost 5 to 10 per cent of its strength, and the seventh specimen when it has lost some 75 per cent of its strength. There were originally about 840 tension test specimens exposed at each site. The number of tension test specimens removed to date is shown in Table G. The results of tensile strength and elongation tests on the 1553 wires removed prior to 1947 have been published in previous reports. The results of tests on 307 specimens removed in 1947 and 1948 are shown in Table VI at the end of this report.

TABLE G.—NUMBER OF TENSILE STRENGTH SPECIMENS REMOVED FOR TEST.

Exposure Site	Number of Wires Removed in 1947 and 1948				Wires Removed Prior to 1947	Total Removed to Date
	Bare Steel	Zinc-Coated	Lead-Coated	Other Types		
Pittsburgh, Pa.	8	47	4	0	599	658
Sandy Hook, N. J.	4	48	0	0	310	362
Bridgeport, Conn.	7	43	0	0	257	307
State College, Pa.	0	13	0	0	105	118
All Other Sites	133	0	0	0	282	415
Total	152	151	4	0	1553	1860

The lead-coated wires removed from the Pittsburgh site during 1947 were the first lead-coated wires to show a loss of tensile strength. Previous tests, made after 1½, 3½, and 6½ yr. of exposure had shown no significant decrease in tensile strength of these lead-coated wires. The 1947 test ($10\frac{1}{2}$ yr. of exposure) showed a tensile strength loss of 9 per cent for wire No. 040, 11 per cent for wire No. 041, 9 per cent for wire No. 042, and 21 per cent for wire No. 043. The No. 043 wire is the smallest lead-coated wire of the lot.

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[2] Report of Wire Inspection Committee on Field Tests of Wire and Wire Products, *Proceedings*, Am. Soc. Testing Mats., Vol. 47, p. 120 (1947).

None of the zinc-coated specimens taken from Pittsburgh, Sandy Hook, Bridgeport, or State College showed any significant deviation from the previously reported rate of tensile strength loss.

TABLE H.—LOSS OF TENSILE STRENGTH—UNCOATED STEEL WIRES.

Exposure Site	Loss in Tensile Strength, per cent Per Yr. Exposure				
	No. 14½ Gage	No. 12½ Gage	No. 11 Gage	No. 9 Gage	No. 6 Gage
Pittsburgh, Pa.	14	10	7	6	4
Sandy Hook, N. J.	10	6	4	3	2
Bridgeport, Conn.	6	3	2	2	1
State College, Pa.	5	2	2	2	1
Lafayette, Ind.	4	2	2	2	1
Santa Cruz, Calif.	3	2	1	1	.
Ithaca, N. Y.	3	2	1	1	.
Ames, Iowa	3	2	1	1	.
College Sta., Texas	2	1	1	.	.
Davis, Calif.	2	1	.	.	.
Manhattan, Kans.	1	.		.	.

On the basis of tests to date the loss in tensile strength by uncoated steel wires expressed in per cent per year of exposure for the various gages of wires is as shown in Table H. Although these data are for uncoated wire, other data have indicated that after the coating has gone, the rate of loss is the same whether wires were previously coated or not.

Findings from Weight-Loss Specimens:

At the start of the test, zinc-coated unfabricated wire specimens were exposed at Pittsburgh, Sandy Hook, and State College to determine the rate of loss of coating. These tests have now been completed and summarized in the 1947 report. The over-all average annual loss of coating in ounces per square foot of surface at Pittsburgh is 0.369; at Sandy Hook it is 0.117; and at State College it is 0.060.

Respectfully submitted on behalf of the Subcommittee,

A. P. JAHN,
Chairman.

TABLE I - REPORT OF INSPECT

Abbreviations and symbols used to designate appearance or states of corrosion: M = metallic, G = gray, Y = yellowed, or rust stained, but not showing actual rough rust of base metal. R = rust of base metal. PHR, PHY = rust or yellowed in pinholes. B, Br, Gn, respectively, signify corroded to a black, brown, or green appearance, D = dark (dirt or soot) to the exclusion of a better observation. Cr = yellow from chromate treatment. MG = intermediate between M and G. Gy = predominately gray but showing indication of Y. Figures (as 5, 20, 50, 100) are percentages.

Coating Group	Average Coating, oz. per sq.ft.of Surface[a]	Wire	State College, Pa.				Lafayette, Ind.		Ames, Iowa		Manhattan, Kans.		Ithaca, N.Y.		Santa Cruz,Cal.		College Sta., Tex.		Davis,Ca
			10.29 Yr.	10.77 Yr.	11.28 Yr.	11.78 Yr.	10.92 Yr.	11.95 Yr.	11.04 Yr.	11.90 Yr.	10.86 Yr.	11.90 Yr.	10.82 Yr.	12.00 Yr.	10.86 Yr.	11.85 Yr.	10.83 Yr.	11.83 Yr.	10.86 Yr.
0.20 to 0.30 Avg. 0.28	0.27	No. 512	100R	100R	100R	100R	100R	100R	100R	100R	80R	80R	100R	100R	GY	GY	100R	100R	GY
	0.30	No. 410	100R	100R	100R	100R	100R	100R	100R	100R	90R	75R	100R	100R	GY	GY	100R	100R	10R
	0.28	No. 411	100R	100R	100R	100R	100R	100R	100R	100R	5R	GY	100R	100R	GY	GY	3R	4R	G
	0.29	No. 510	100R	100R	100R	100R	100R	100R	100R	100R	5R	1R	100R	100R	GY	GY	5R	10R	G
	0.29	No. 412	100R	100R	100R	100R	100R	100R	100R	100R	5R	15R	100R	100R	GY	GY	4R	10R	G
	0.24	No. 511	100R	100R	100R	100R	100R	100R	100R	100R	20R	30R	100R	100R	GY	10R	82R	90R	G
0.25 to 0.35 Avg. 0.30	0.25	No. 315	100R	100R	100R	100R	100R	100R	100R	100R	60R	90R	100R	100R	GY	36R	92R	99R	GY
	0.28	No. 215	100R	100R	100R	100R	100R	100R	100R	100R	70R	75R	100R	100R	GY	29R	58R	75R	GY
	0.27	No. 117	100R	100R	100R	100R	100R	100R	100R	100R	60R	30R	100R	100R	GY	GY	47R	55R	GY
	0.38	No. 317	100R	100R	100R	100R	100R	100R	36R	74R	GY	GY	100R	100R	GY	GY	2R	4R	G
	0.36	No. 217	100R	100R	100R	100R	100R	100R	100R	100R	10R	10R	100R	100R	GY	GY	3R	6R	G
	0.32	No. 316	100R	100R	100R	100R	100R	100R	100R	100R	5R	10R	100R	100R	GY	GY	62R	2R	G
	0.30	No. 216	100R	100R	100R	100R	100R	100R	100R	100R	5R	GY	100R	100R	GY	GY	1R	1R	G
	0.25	No. 115	100R	100R	100R	100R	100R	100R	100R	100R	50R	75R	100R	100R	GY	25R	49R	72R	1R
0.35 to 0.45 Avg. 0.38	0.36	No. 520	100R	100R	100R	100R	100R	100R	100R	100R	10R	GY	100R	100R	GY	GY	TrR	4R	G
	0.35	No. 422	100R	100R	100R	100R	100R	100R	94R	100R	5R	15R	100R	100R	GY	GY	TrR	3R	G
	0.31	No. 423	100R	100R	100R	100R	100R	100R	100R	100R	5R	15R	100R	100R	GY	GY	TrR	3R	G
	0.44	No. 522	100R	100R	100R	100R	100R	100R	93R	99R	10R	GY	100R	100R	GY	GY	TrR	3R	G
	0.37	No. 282	100R	100R	100R	100R	100R	100R	89R	96R	5R	GY	100R	100R	GY	GY	2R	4R	G
	0.38	No. 521	100R	100R	100R	100R	100R	100R	77R	88R	10R	GY	100R	100R	GY	GY	TrR	3R	G
	0.47	No. 421	100R	100R	100R	100R	100R	100R	91R	97R	5R	15R	100R	100R	GY	GY	1R	3R	G
0.45 to 0.55 Avg. 0.47	0.44	No. 325	100R	100R	100R	100R	100R	100R	3R	6R	5R	GY	100R	100R	GY	GY	1R	3R	G
	0.50	No. 228	100R	100R	100R	100R	100R	100R	17R	19R	3R	GY	100R	100R	GY	GY	1R	4R	G
	0.54	No. 329	80R	99R	100R	100R	100R	100R	8R	14R	2R	5R	100R	100R	GY	GY	3R	5R	G
	0.52	No. 227	50R	90R	90R	100R	100R	100R	1R	3R	3R	GY	95R	100R	GY	GY	1R	3R	G
	0.41	No. 125	100R	100R	100R	100R	100R	100R	66R	95R	25R	15R	100R	100R	GY	GY	3R	6R	G
	0.54	No. 127	90R	100R	100R	100R	100R	100R	2R	3R	10R	1R	99R	100R	GY	GY	3R	5R	G
	0.38	No. 326	95R	100R	100R	100R	100R	100R	9R	2R	GY	GY	100R	100R	GY	G	1R	2R	G
	0.45	No. 226	50R	95R	98R	100R	100R	100R	1R	3R	1R	GY	86R	99R	GY	G	1R	4R	G
	0.47	No. 327	90R	100R	100R	100R	100R	100R	G	3R	1R	GY	100R	100R	GY	GY	1R	1R	G
	0.45	No. 225	80R	100R	100R	100R	100R	100R	G	G	1R	Y	100R	100R	GY	GY	1R	1R	G
0.50 to 0.60 Avg. 0.56	0.61	No. 530	G	G	1R	50R	100R	100R	G	G	MG	MG	3R	100R	MG	MG	G	G	MG
	0.57	No. 432	G	1R	5R	20R	67R	100R	G	G	MG	MG	1R	94R	MG	MG	G	G	MG
	0.60	No. 531	40R	99R	99R	100R	100R	100R	G	10R	G	G	100R	100R	MG	MG	G	G	G
	0.48	No. 431	10R	100R	100R	100R	100R	100R	G	15R	1R	G	100R	100R	GY	G	2R	3R	G
	0.54	No. 430	50R	95R	95R	100R	100R	100R	1R	4R	GY	G	76R	100R	GY	G	1R	1R	G
0.60 to 0.70 Avg. 0.65	0.69	No. 338	G	G	G	1R	4R	29R	G	G	MG	MG	M	2R	MG	MG	G	G	MG
	0.68	No. 236	G	G	G	G	3R	28R	G	G	MG	MG	M	MG	MG	MG	G	G	MG
	0.61	No. 335	70R	95R	100R	100R	100R	100R	1R	1R	G	G	99R	100R	G	MG	G	G	G
	0.63	No. 237	20R	25R	30R	35R	54R	90R	1R	1R	MG	G	18R	44R	MG	MG	G	G	G
	0.74	No. 135	1R	10R	15R	30R	66R	100R	G	G	G	G	5R	57R	G	MG	G	G	G
	0.57	No. 337	15R	90R	90R	100R	100R	100R	4R	5R	5R	5R	72R	100R	GY	MG	4R	5R	G
	0.67	No. 235	GY	1R	2R	10R	69R	95R	G	G	1R	GY	1R	13R	GY	GY	2R	4R	G
	0.65	No. 239	1R	15R	20R	80R	100R	100R	1R	1R	3R	G	1R	36R	GY	GY	1R	3R	G
	0.67	No. 138	GY	30R	35R	80R	100R	100R	5R	5R	7R	GY	48R	80R	GY	GY	2R	5R	G
	0.64	No. 139	10R	50R	50R	70R	91R	99R	5R	5R	10R	10R	35R	64R	GY	GY	6R	9R	G
	0.66	No. 336	1R	20R	30R	100R	99R	100R	2R	4R	5R	GY	28R	89R	GY	GY	1R	3R	G
	0.60	No. 238	20R	80R	80R	95R	100R	100R	2R	2R	5R	GY	57R	99R	GY	GY	1R	3R	G
0.70 to 0.85 Avg. 0.75	0.70	No. 540	G	G	G	G	G	40R	G	G	MG	MG	G	1R	G	MG	G	G	G
	0.72	No. 442	G	G	G	G	MG	2R	G	G	MG	MG	M	5R	MG	MG	G	G	MG
	0.79	No. 543	5R	10R	15R	25R	37R	65R	G	G	MG	MG	5R	18R	G	MG	G	G	G
	0.78	No. 441	GY	5R	5R	10R	20R	85R	2R	2R	MG	MG	GY	1R	G	MG	G	G	G
	0.70	No. 542	GY	10R	15R	75R	100R	100R	G	G	G	G	79R	100R	MG	MG	G	G	G
	0.74	No. 443	GY	10R	10R	20Y	46R	98R	G	G	MG	MG	3R	14R	G	MG	G	G	G
	0.74	No. 495	GY	GY	GY	GY	7R	78R	G	G	Cr	Cr	GY	1R	-	-	Cr	Cr	-
	0.76	No. 541	Y	10R	15R	90R	100R	100R	G	G	1R	G	18R	100R	GY	GY	1R	3R	G
	0.76	No. 440	25R	95R	99R	100R	100R	100R	G	G	5R	G	95R	100R	GY	GY	1R	3R	G
	0.87	No. 444	Y	1R	1R	30R	93R	99R	G	G	1R	G	GY	1R	GY	GY	2R	3R	G
0.80 to 1.00 Avg. 0.88	1.05	No. 348	G	G	G	G	G	G	G	G	MG	MG	M	MG	MG	MG	G	G	MG
	0.81	No. 248	G	G	G	G	G	75R	G	G	MG	MG	M	1R	MG	G	G	G	MG
	0.88	No. 347	GY	GY	G	G	G	GY	G	G	MG	MG	G	GY	G	MG	G	G	MG
	0.95	No. 246	GY	GY	G	G	1R	7R	G	G	MG	MG	GY	GY	G	MG	G	G	MG
	0.88	No. 346	Y	GY	Y	1R	1R	84R	G	G	G	G	GY	GY	G	G	G	G	G
	0.81	No. 245	Y	5R	10R	25R	73R	97R	G	G	G	G	2R	24R	G	G	G	G	G
	0.81	No. 296	GY	GY	GY	GY	G	1R	G	G	Cr	Cr	GY	G	-	-	-	-	-
	0.90	No. 148	GY	Y	GY	GY	10R	35R	G	G	G	MG	GY	GY	MG	G	G	G	G
	0.85	No. 149	GY	1R	1R	1R	32R	66R	G	G	MG	MG	1R	1R	MG	MG	G	G	G
	0.84	No. 345	Y	3R	10R	30R	88R	96R	G	G	2R	GY	4R	10R	GY	G	2R	3R	G
	0.96	No. 247	Y	Y	Y	1R	48R	88R	G	G	3R	GY	GY	GY	GY	G	2R	4R	G
Avg. 1.28	1.35	No. 800	GY	GY	GY	GY	G	GY	G	G	MG	MG	GY	GY	-	-	G	G	-
	1.20	No. 801	GY	GY	GY	GY	G	GY	G	G	MG	MG	GY	GY	-	-	G	G	-
1.60 to 1.80 Avg. 1.76	2.08	No. 552	G	G	G	G	MG	G	G	G	MG	MG	M	MG	MG	MG	G	G	MG
	1.83	No. 451	G	G	G	G	MG	G	G	G	MG	MG	M	MG	MG	MG	G	G	MG
	1.75	No. 350	G	G	G	G	MG	G	G	G	MG	MG	M	MG	MG	MG	G	G	MG
	1.69	No. 252	G	G	G	G	MG	G	G	G	MG	MG	M	MG	MG	MG	G	G	MG
	1.65	No. 351	G	G	G	G	G	G	G	G	MG	MG	MG	MG	G	MG	G	G	MG
	1.76	No. 250	G	G	G	G	MG	G	G	G	MG	MG	MG	MG	MG	MG	G	G	G
	1.69	No. 551	G	G	G	G	MG	G	G	G	MG	MG	M	MG	G	G	G	G	MG
	1.50	No. 450	G	G	G	G	MG	G	G	G	MG	MG	M	MG	G	G	G	G	MG
	1.75	No. 352	G	G	G	G	G	G	G	G	MG	MG	M	MG	G	G	G	G	G
	1.86	No. 251	G	G	G	G	MG	G	G	G	MG	MG	MG	G	G	MG	G	G	G
	1.86	No. 151	G	G	G	G	G	G	G	G	MG	MG	MG	G	G	MG	G	G	MG
Heavy Avg. 2.89	2.80	No. 397	G	G	G	G	MG	G	G	G	MG	MG	M	MG	G	MG	G	G	MG
	2.72	No. 298	G	G	G	G	MG	G	G	G	MG	MG	M	MG	MG	MG	G	G	MG
	3.00	No. 299	G	G	G	G	MG	G	G	G	MG	MG	M	MG	-	-	G	G	-

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[a] The zinc coating weight reported in this column is the average of all stripping test determinations made on samples of unfabricated wire, fence or barbed wire of the specific wire lot number.

NSPECTIONS OF UNFABRICATED WIRE SPECIMENS

res.

vis,Cal. 11.85 Yr.
13R
15R
1R
5R
GY
10R
26R
GY
10R
G
G
2R
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5R
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REPORT OF COMMITTEE A-5; WIRE INSPECTION REPORT

Abbreviations and symbols used to designate appearance or states of corrosion: M = metallic, G = gray, Y = yellowed, or rust stained, but not showing actual rough rust of base metal. (In cases of zinc coatings, the G and Y conditions are characteristic states of corrosion of zinc iron alloys in the coatings.) R = rust of base metal. MG = intermediate between M and G. GY predominately gray but showing indication of Y. Figures (as 5, 20, 50, 100) are percentages.

Coating Group[b]	Average Coating, oz. per sq. ft. of Surface[a]	Wire Lot	SANDY HOOK, N.J. 10.43 Yr.	SANDY HOOK, N.J. 10.92 Yr.	SANDY HOOK, N.J. 11.44 Yr.	SANDY HOOK, N.J. 11.92 Yr.	BRIDGEPORT, CONN. 10.43 Yr.	BRIDGEPORT, CONN. 10.92 Yr.	BRIDGEPORT, CONN. 11.44 Yr.	BRIDGEPORT, CONN. 11.93 Yr.
Avg. 1.28	1.35	No. 800.....	20R	45R	50R	90R	25R	85R	90R	95R
	1.20	No. 801.....	90R	99R	100R	100R	98R	99R	99R	99R
1.60 to 1.80	2.08	No. 552.....	G	G	G	G	GY	GY	GY	GY
	1.83	No. 451.....	G	G	G	G	GY	GY	GY	GY
	1.75	No. 350.....	G	G	G	G	GY	GY	GY	GY
	1.69	No. 252.....	G	G	G	G	GY	GY	GY	GY
	1.65	No. 351.....	1R	1R	1R	2R	2R	10R	10R	10R
	1.76	No. 250.....	G	1R	1R	2R	1R	5R	10R	10R
	1.69	No. 551.....	G	G	G	G	GY	GY	GY	GY
	1.50	No. 450.....	G	G	G	1R	3R	15R	25R	60R
	1.75	No. 352.....	G	1R	G	1R	GY	10R	10R	10R
	1.86	No. 251.....	10R	10R	10R	15R	7R	5R	10R	10R
Avg. 1.76	1.86	No. 151.....	15R	50R	50R	50R	1R	5R	5R	10R
Heavy Avg. 2.89	2.80	No. 397.....	G	G	G	G	GY	GY	GY	GY
	2.72	No. 298.....	G	G	G	G	GY	GY	GY	GY
	3.00	No. 299.....	G	G	G	G	GY	GY	GY	GY

a. The zinc coating weight reported in this column is the average of all stripping test determination made on samples of unfabricated wire, fence or barbed wire of the specific wire lot number.

b. All other coating weight groups were 100R at 10.43 Yr. except that: In Coating Group 0.80 to 1.00 at Sandy Hook
Wire No. 348 was 1R at 10.43 Yr., 90R at 10.92 Yr. and 100R at 11.44 Yr.
Wire No. 246 was 85R at 10.43 Yr., 99R at 10.92 Yr. and 100R at 11.44 Yr.

In Coating Group 0.80 to 1.00 at Bridgeport
Wire No. 348 was 90R at 10.43 Yr., 100R at 10.92 Yr.

Abbreviations and symbols used to designate appearance or states of corrosion: M = metallic, G = gray, Y = yellowed, R = rust of base metal, PHR, PHY = rust or yellowed in pinholes. B, Br, Gn, respectively, signify corroded to a black, brown, or green appearance. D = dark (dirt or soot) to the exclusion of a better observation. MG = intermediate between M and G. GY predominately gray but showing indication of Y. SY* or SR* indicate, respectively: superficial Y and superficial, R, the asterisk denoting a speckled appearance. Figures (as 5, 20, 50, 100) are percentages. R+Y = indistinguishable proportions of R and Y.

	Gage	Wire	Sandy Hook, N. J. 10.43 Yr.	Sandy Hook, N. J. 10.92 Yr.	Sandy Hook, N. J. 11.44 Yr.	Sandy Hook, N. J. 11.92 Yr.	Bridgeport, Conn, 10.43 Yr.	Bridgeport, Conn, 10.92 Yr.	Bridgeport, Conn, 11.44 Yr.	Bridgeport, Conn, 11.93 Yr.	State College, Pa. 10.29 Yr.	State College, Pa. 10.77 Yr.	State College, Pa. 11.28 Yr.	State College, Pa. 11.78 Yr.
Copper-covered wire	11	No. 021, 7.42-oz.	Gn	Gn	Gn	Gn	Gn	Gn	Gn	Gn	Gn	Gn	Gn	Gn
	9	No. 022, 9.24-oz.	Gn	Gn	Gn	Gn	Gn	Gn	Gn	Gn	Gn	Gn	Gn	Gn
Lead-coated Wires	6	No. 040, 1.40-oz.	100R+Y	100R+Y	100R+Y	100R+Y	2R	1R	5R	1R	100R+Y	100R+Y	100R+Y	100R+Y
	9	No. 041, 1.48-oz.	100R+Y	100R+Y	100R+Y	100R+Y	1R	1R	2R	1R	100R+Y	100R+Y	100R+Y	100R+Y
	11	No. 042, 1.68-oz.	100R+Y	100R+Y	100R+Y	100R+Y	1R	2R	2R	1R	100R+Y	100R+Y	100R+Y	100R+Y
	14-1/2	No. 043, 1.90-oz.	100R+Y	100R+Y	100R+Y	100R+Y	1R	1R	1R	1R	100R+Y	100R+Y	100R+Y	100R+Y
Corrosion-Resistant Uncoated Wires:														
12-14% Cr., Cold drawn	12	No. 001	Y	YSR	Y	YSR	GY	Y	GY	GY	M	MG	M	MG
	9	No. 004	Y	YSR	Y	Y	GY	Y	GY	GY	M	MG	M	MG
	17	No. 005	Y	YSR	Y	Y	GY	Y	GY	GY	M	MG	M	MG
12-14% Cr., air quenched	13	No. 002	Y	YSR	Y	Y	GY	GY	GY	GY	M	MG	M	MG
	10	No. 006	Y	YSR	Y	Y	GY	GY	GY	GY	M	MG	M	MG
	18	No. 007	Y	YSR	Y	Y	GY	GY	GY	GY	M	MG	M	MG
18% Cr., 8% Ni.	15	No. 003	MG	MG	MG	GY	MG	MG	MG	MG	M	M	M	M
	12	No. 008	MG	MG	MG	GY	MG	MG	MG	MG	M	M	M	M
	20	No. 009	MG	MG	MG	GY	MG	MG	MG	MG	M	M	M	M
	14	No. 015	MG	MG	MG	GY	MG	MG	MG	MG	M	M	M	M

	Gage	Wire	Lafayette, Ind. 10.92 Yr.	Lafayette, Ind. 11.95 Yr.	Ames, Iowa 11.04 Yr.	Ames, Iowa 11.90 Yr.	Manhattan, Kans. 10.86 Yr.	Manhattan, Kans. 11.90 Yr.	Ithaca, N.Y. 10.82 Yr.	Ithaca, N.Y. 12.00 Yr.	Santa Cruz, Calif 10.86 Yr.	Santa Cruz, Calif 11.85 Yr.	College Sta., Texas 10.83 Yr.	College Sta., Texas 11.83 Yr.	Davis, Calif. 10.86 Yr.	Davis, Calif. 11.85 Yr.
Copper-covered wire	11	No. 021, 7.42-oz.	Gn	Gn	Br	Br	Br	Br	Br	B	Br	Br	Br	Br	Br	Br
	9	No. 022, 9.24-oz.	Gn	Gn	Br	Br	Br	Br	Br	B	Br	Br	Br	Br	Br	Br
Lead-coated Wires	6	No. 040, 1.40-oz.	69PHR	100PHR	10R	6R	5R*	GY	6R	5R	19SR	19SR	12PHY	14R+Y	21SR	22SR
	9	No. 041, 1.48-oz.	51PHR	90PHR	28R	39R	10R	1SR	9R	10R	39SR	46SR	33PHY	28R+Y	57SR	63SR
	11	No. 042, 1.68-oz.	68PHR	90PHR	12R	24R	5R	15R	5R	5R	17SR	21SR	23PHY	25R+Y	24SR	24SR
	14-1/2	No. 043, 1.90-oz.	31PHR	25PHR	7R	13R	7R	GY	2R	5R	19SR	25SR	2PHY	G	18SR	19SR
Corrosion-Resistant Uncoated Wires:																
12-14% Cr., Cold drawn	12	No. 001	M	M	SY	SY	10PHR	G	Y*	SY	73SR	75SR	100R+Y	100R+Y	48SR	48SR
	9	No. 004	M	M	SY	SY	GY	MG	Y*	SY	58SR	60SR	96R+Y	96R+Y	45SR	45SR
	117	No. 005	M	M	SY	SY	GY	MG	Y*	SY	62SR	75SR	99R+Y	98R+Y	51SR	54SR
12-14% Cr., air quenched	13	No. 002	M	M	SY	SY	GY	MG	M	SY	26SR	26SR	81R+Y	75R+Y	18SR	18SR
	10	No. 006	M	M	SY	SY	MG	M	M	SY	19SR	24SR	75R+Y	56R+Y	13SR	14SR
	18	No. 007	M	M	SY	SY	MG	M	Y*	SY	29SR	52SR	89R+Y	91R+Y	20SR	22SR
18% Cr., 8% Ni.	15	No. 003	M	M	M	M	M	M	M	M	MG	MG	M	M	MG	MG
	12	No. 008	M	M	M	M	M	M	M	M	MG	MG	M	M	MG	MG
	20	No. 009	M	M	SY	SY	M	M	M	M	MG	MG	M	M	MG	MG
	14	No. 015	M	M	SY	SY	M	M	M	M	-	-	M	M	-	-

TABLE II.—REPORT OF INSPECTIONS OF BARBED WIRE SPECIMENS.

Abbreviations and symbols used to designate appearance or states of corrosion: M = metallic; G = gray; Y = yellowed, or rust stained, but not showing actual rough rust of base metal; R = rust of base metal; PHR, PHY = rust or yellowed in pinholes; B, Br, Gn, respectively, signify corroded to a black, brown, or green appearance; D = dark (dirt or soot) to the exclusion of a better observation; MG = intermediate M and G; GY predominately gray but showing indication of Y; RB = rust on barbs; SR = superficial rust; asterisk (*) = speckled; R+Y = indistinguishable proportions of R and Y.

Coating Group	Average Coating, oz. per sq. ft. of surface[a]	Wire[b]	State College, Pa.				Lafayette, Ind.		Ames, Iowa		Manhattan, Kans.		Ithaca, N. Y.		Santa Cruz, Calif.		College Station, Tex.		Davis, Calif.	
			9.40 yr.	9.89 yr.	10.43 yr.	10.90 yr.	10.92 yr.	11.95 yr.	11.04 yr.	11.90 yr.	10.86 yr.	11.90 yr.	10.82 yr.	12.00 yr.	10.86 yr.	11.85 yr.	10.83 yr.	11.83 yr.	10.86 yr.	11.85 yr.
0.20 to 0.30	0.30	No. C410	100R	100R	100R	100R	100R	100R	100R	100R	75R	50R	100R	100R	GY	GY	20R	50R	G	10R
	0.24	No. C411	100R	100R	100R	100R	100R	100R	100R	100R	10R	10R	100R	100R	GRB	GRB	10R	65R	GRB	10R
	0.29	No. C412	100R	100R	100R	100R	100R	100R	100R	100R	GY	GY	100R	100R	GY	GY	5R	45R	G	G
0.35 to 0.45	0.37	No. C421	100R	100R	100R	100R	100R	100R	50R	60R	GY	GY	100R	100R	GY	GY	GY	2R	G	G
	0.47	No. C422	100R	100R	100R	100R	100R	100R	30R	40R	GY	GY	85R	90R	GY	GY	2R	5R	G	G
	0.31	No. C420	100R	100R	100R	100R	100R	100R	100R	100R	GY	GY	100R	100R	GY	GY	3R	5R	G	G
0.50 to 0.60	0.48	No. C430	70R	90R	100R	100R	100R	100R	GRB	GRB	G	GY	45R	100R	GY	GY	2R	2R	G	G
	0.54	No. C431	40R	80R	50R	90R	95R	95R	10R	10R	GY	GY	10R	10R	GY	GY	5R	2R	G	G
	0.57	No. C432	G	GRB	GRB	GRB	25R	95R	GRB	GRB	MG	MG	MRB	5R	MG	MG	G	G	MG	MG
0.70 to 0.85	0.72	No. C441	G	GRB	G	GRB	GRB	2R	GRB	GRB	MG	MG	GRB	GRB	MG	MG	G	G	MG	MG
	0.78	No. C442	G	GRB	GRB	GRB	GRB	10R	G	G	MG	MG	GRB	GRB	G	G	G	G	MG	MG
	0.74	No. C443	GY	GRB	GY	GRB	30R	90R	G	G	MG	MG	2R	5R	G	G	G	G	MG	MG
0.80 to 1.00	0.97	No. C445	GY	GY	G	GY	G	GY	G	G	MG	MG	G	G	G	G	G	G	MG	MG
	0.92	No. C446	G	GY	G	GY	5R	10R	G	G	G	MG	GRB	GRB	G	G	G	G	MG	MG
1.60 to 1.80	1.64	No. C450	GY	GY	G	GY	G	Y	G	G	MG	MG	MG	GY	G	G	G	G	MG	MG
	1.50	No. C452	G	G	G	G	G	G	G	G	MG	MG	MG	G	G	G	G	G	MG	MG
	1.83	No. C451	G	G	G	GRB	5R	GRB	G	GRB	MG	MG	GRB	GRB	G	MG	G	G	MG	MG
Heavy Coating	1.99	No. C494	G	G	G	G	MG	G	G	G	MG	MG	M	M	G	G	G	G	MG	MG
	1.99	No. C494	G	G	G	G	MG	G	G	G	MG	MG	M	M	G	G	G	G	MG	MG
	2.00	No. C447	G	G	G	G	5R	GRB	G	G	MG	MG	MRB	MRB	G	MG	G	G	MG	MG
Copper-covered (3.97 oz. per sq. ft.)		No. C025	Gn	GnRB	GnRR	GnRB	Gn	Gn	....	Br	B	Br	Gn	Gn	BrRB	BrRB	Br	Br	BrRB	BrRB
		No. C025	Gn	GnRB	GnRR	GnRB	....	....	Br	....	....	....	Gn	Gn	....	....	....	....	....	....
Lead-coated (1.83 oz. per sq. ft.)		No. C045	....	....	....	....	30PHR	50PHR	5R	10R	10R	5PHY	5R	10R		....	25R+Y	3R	25SR	25SR
		No. C045	....	....	....	....	40PHR	50PHR	5R	10R	....	....	....	....	25SR	25SR	25R+Y	3R	....	....

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[a] The zinc coating weight reported in this column is the average of all stripping test determinations made on samples of unfabricated wire, fence or barbed wire of the specific wire lot number.

[b] These barbed wire numbers do not always correspond to the unfabricated wire numbers as seen opposite:

Barbed Wire	Unfabricated Wire	Barbed Wire	Unfabricated Wire
No. C410	No. 410	No. C441	No. 442
No. C411	....	No. C442	No. 441
No. C412	No. 412	No. C443	No. 443
No. C421	....	No. C445	....
No. C422	No. 421	No. C446	....
No. C420	No. 423	No. C447	....
No. C430	No. 431	No. C450	....
No. C431	No. 430	No. C452	No. 450
No. C432	No. 432	No. C451	No. 451
		No. C494	....

TABLE III.—REPORT OF INSPECTIONS

Abbreviations and symbols used to designate appearance or states of corrosion: M = metallic; G = gray; Y = yellowed, or holes: B, Br, Gn, respectively signify corroded to a black, brown, or green appearance; D = dark (dirt or soot) to the exclusion or SR = superficial Y and superficial R, respectively; Asterisk (*) = speckled appearance. Figures (as 5, 20, 50, 100) are per- stay wires. Where two values are shown separated by & (90R&Y) the first applies to the top wires of the fence and the second to

Coating Group	Average Coating, oz. per sq. ft. of surface[a]	Fence	State College, Pa.				Lafayette, Ind.		Ames, Iowa		Manhattan, Kans.	
			9.40 yr.	9.89 yr.	10.43 yr.	10.90 yr.	10.92 yr.	11.95 yr.	11.04 yr.	11.90 yr.	10.86 yr.	11.90 yr.
0.20 to 0.30 Avg. 0.28	0.27	No. 512.	100R	100R	100R	100R	100R	100R	100R	100R	30R	50R
	0.30	No. 410...	100R	100R	100R	100R	100R	100R	100R	100R	50R	50R
	0.28	No. 411...	100R	100R	100R	100R	100R	100R	100R	100R	Y	GY
	0.29	No. 510...	100R	100R	100R	100R	100R	100R	100R	100R	GY	GY
	0.29	No. 412..	100R	100R	100R	100R	100R	100R	100R	100R	G	GY
	0.24	No. 511...	100R	100R	100R	100R	100R	100R	100R	100R	25R	25R
0.25 to 0.35 Avg. 0.30	0.25	No. 315 .	100R	100R	100R	100R	100R	100R	50R	100R	50R	50R
	0.28	No. 215...	100R	100R	100R	100R	100R	100R	100R	100R	20R	50R
	0.38	No. 317...	100R	100R	100R	100R	90R	100R	50R	100R	GY	GY
	0.32	No. 316...	100R	100R	100R	100R	95R	100R	50R	100R	GY	GY
	0.30	No. 216...	100R	100R	100R	100R	90R	100R	50R	100R	GY	GY
0.35 to 0.45 Avg. 0.38	0.36	No. 520..	100R	100R	100R	100R	95R	100R	50R	60R	GY	GY
	0.35	No. 422..	100R	100R	100R	100R	90R	100R	50R	50R	GY	GY
	0.31	No. 423..	100R	100R	100R	100R	90R	100R	50R	50R	GY	GY
	0.44	No. 522..	50R	90R	90R	100R	90R	100R	10R	50R	GY	G
	0.38	No. 521..	100R	100R	100R	100R	90R	100R	80R	50R	GY	GY
	0.47	No. 421..	50R	100R	100R	100R	80R	100R	5R	15R	GY	GY
0.45 to 0.55 Avg. 0.46	0.44	No. 325...	50R	90R	95R	100R	90R	100R	10R	5R	TrR	GY
	0.50	No. 228...	40R	50R	100R	100R	100R	100R	G	5R	GY	GY
	0.51	No. 227...	80R	85R	100R	100R	80R	100R	5R	10R	GY	GY
	0.38	No. 326...	99R	100R	100R	100R	90R	100R	50R	50R	G	GY
	0.47	No. 327...	T/R	50R	50R	100R	80R	100R	G	G	G	GY
	0.45	No. 225...	Y	20R	50R	100R	80R	100R	G	1R	GY	GY
0.50 to 0.60 Avg. 0.54	0.61	No. 530...	G	G	G	G	40R	100R	G	G	MG	MG
	0.57	No. 432...	G	G	G	G	5R	60R	G	G	MG	MG
	0.60	No. 531...	GY	25R	50R	50R	40R	100R	25R	25R	G	G
	0.48	No. 431...	10R	90R	70R	90R	80R	100R	GY	1R	GY	GY
	0.54	No. 430...	20R	90R	80R	95R	85R	100R	25R	10R	GY	GY
	0.49	No. 532...	60R	100R	100R	100R	90R	100R	G	G	GY	GY
	0.49	No. 433...	20R	50R	60R	100R	90R	100R	GY	G	GY	GY
0.60 to 0.70 Avg. 0.64	0.69	No. 338...	G	G	G	G	G	G	G	G	MG	MG
	0.68	No. 236...	G	G	G	G	G	G	G	G	MG	MG
	0.61	No. 335...	GY	10R	20R	50R	80R	90R	G	G	G	G
	0.63	No. 237...	GY	20R	40R	50R	70R	70R	G	G	G	G
	0.57	No. 337...	Y	20R	30R	80R	75R	80R	G	G	GY	GY
	0.67	No. 235...	Y	50R	50R	60R	90R	100R	G	G	GY	GY
	0.66	No. 336...	Y	20R	20R	50R	60R	80R	G	G	GY	GY
	0.60	No. 238...	Y	40R	50R	50R	70R	100R	G	G	GY	GY
0.70 to 0.85 Avg. 0.74	0.70	No. 540...	G	G	G	G	G	10R	G	G	MG	MG
	0.72	No. 442...	G	G	G	G	G	G	G	G	MG	MG
	0.79	No. 543...	G	GY	5R	5R	40R	50R	G	G	MG	MG
	0.78	No. 441...	GY	G	G	GY	15R	80R	G	G	MG	MG
	0.70	No. 542...	GY	5R	5R	10R	50R	50R	G	G	MG	G
	0.74	No. 443...	GY	GY	GY	10R	40R	40R	G	G	MG	MG
	0.76	No. 541...	GY	GY	G	1R	30R	50R	G	G	MG	MG
	0.76	No. 440...	GY	G	G	GY	20R	50R	G	G	MG	MG
0.80 to 1.00 Avg. 0.90	1.05	No. 348...	G	G	G	G	G	G	G	G	MG	MG
	0.81	No. 248..	G	G	G	G	G	G	G	G	MG	MG
	0.88	No. 347...	G	G	G	G	G	5R	G	G	MG	G
	0.95	No. 246...	G	GY	GY	GY	10R	40R	G	G	MG	MG
	0.88	No. 346...	GY	GY	GY	GY	10R	40R	G	G	G	G
	0.81	No. 245...	GY	GY	GY	GY	30R	80R	G	G	MG	G
	0.84	No. 345...	Y	Y	Y	Y	15R	50R	G	G	GY	GY
	0.96	No. 247...	Y	Y	Y	Y	10R	50R	G	G	GY	GY
1.60 to 1.80	1.75	No. 350...	G	G	G	G	G	G	G	G	MG	MG
	1.69	No. 252...	G	G	G	G	G	MG	G	G	MG	MG
	1.75	No. 352...	G	G	G	G	G	G	G	G	MG	MG
Avg. 2.76	2.80	No. 397...	G	G	G	G	G	G	G	G	MG	MG
	2.72	No. 298...	G	G	G	G	G	G	G	G	MG	MG
12 to 14% Cr, cold drawn.......		No. 001...	G	MG	MG	MG	M	M	SY	SY	MG*	MG*
12 to 14% Cr, air quenched....		No. 002...	MG	MG	MG	MG	M	M	SY	SY	MG	MG
18% Cr, 8% Ni...		No. 003...	M	M	M	M	M	M	M	M	M	M
Copper-covered (7.42 oz. per sq. ft.).......		No. 020...	Y	Gn	Gn	Gn	Gn	Gn	Br	Br	B	Br
Lead-coated (1.48 oz. per sq. ft.)..........		No. 040...	90PHR	100R+Y	100R+Y	100R+Y	40PHR	50PHR	20R	25R	10R	10R

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[a] The zinc coating weight reported in this column is the average of all stripping test determinations made on samples

OF FARM FIELD FENCE SPECIMENS.

rust stained, but not showing actual rough rust of base metal; R = rust of base metal; PHR, PHY = rust or yellowed in pin-
of a better observation; MG = intermediate between M and G; GY = predominately gray but showing indication of Y; SY
centages. Where two values are shown separated by a dash (50R-80R) the first applies to the line wires and the second to the
the bottom wires of the fence. R + Y = indistinguishable proportions of R and Y.

Ithaca, N.Y.		Santa Cruz, Calif.		College Station, Tex.		Davis, Calif.		Coating Group	Average Coating, oz. per sq. ft. of surface[a]	Fence
10.82 yr.	12.00 yr.	10.86 yr.	11.85 yr.	10.83 yr.	11.83 yr.	10.86 yr.	11.85 yr.			
100R	100R	GY	GY	80R	95R	10R	30R	0.20 to 0.30 Avg. 0.28	0.27	No. 512
100R	100R	20R	50R	50R	80R	5R	20R		0.30	No. 410
100R	100R	GY	GY	2R	10R	G	G		0.28	No. 411
100R	100R	GY	GY	5R	20R	G	G		0.29	No. 510
100R	100R	GY	GY	5R	5R	G	G		0.29	No. 412
100R	100R	GY	GY	40R	90R	5R	40R		0.24	No. 511
100R	100R	35R	40R	70R	90R	20R	G	0.25 to 0.35 Avg. 0.30	0.25	No. 315
100R	100R	GY	25R	30R	50R	5R	15R		0.28	No. 215
80R	95R	GY	GY	GY	1R	G	G		0.38	No. 317
85R	100R	30R	30R	2R	2R	G	G		0.32	No. 316
85R	90R	GY	GY	2R	2R	G	G		0.30	No. 216
85R	95R	GY	GY	5R	15R	G	G	0.35 to 0.45 Avg. 0.38	0.36	No. 520
90R	95R	GY	GY	5R	10R	G	G		0.35	No. 422
85R	90R	GY	GY	3R	5R	G	G		0.31	No. 423
70R	90R	GY	GY	GY	5R	G	G		0.44	No. 522
80R	90R	GY	GY	2R	10R	G	G		0.38	No. 21
75R	80R	GY	GY	2R	5R	G	G		0.47	No. 421
45R	80R	GY	GY	5R	8R	G	G	0.45 to 0.55 Avg. 0.46	0.44	No. 325
50R	60R	GY	GY	2R	5R	G	G		0.50	No. 228
50R	70R	GY	GY	1R	4R	G	G		0.51	No. 227
70R	95R	GY	GY	1R	1R	G	G		0.38	No. 326
40R	90R	GY	GY	1R	1R	G	G		0.47	No. 327
25R	60R	GY	GY	1R	2R	G	G		0.45	No. 225
3R	15R	MG	MG	G	G	MG	MG	0.50 to 0.60 Avg. 0.54	0.61	No. 530
M	G	MG	MG	G	G	MG	MG		0.57	No. 432
30R	25R	MG	GY	G	G	MG	MG		0.60	No. 531
40R&G	70R	GY	GY	GY	5R	G	G		0.48	No. 431
50R	50R&MG	GY	GY	GY	2R	G	G		0.54	No. 430
65R	75R	GY	GY	GY	3R	G	G		0.49	No. 532
45R	60R	GY	GY	GY	5R	G	G		0.49	No. 433
M	MG	MG	MG	G	G	MG	MG	0.60 to 0.70 Avg. 0.64	0.69	No. 338
M	MG	G	MG	G	G	MG	MG		0.68	No. 236
10R	30R	G	MG	G	G	MG	MG		0.61	No. 335
5R	40R	G	G	G	G	G	MG		0.63	No. 237
15R	30R	GY	GY	3R	5R	G	G		0.57	No. 337
30R	60R	GY	GY	2R	2R	G	G		6.67	No. 235
10R	25R	GY	GY	5R	5R	G	G		0.66	No. 336
20R	60R	GY	GY	4R	4R	G	G		0.60	No. 238
M	MG	MG	MG	G	G	MG	MG	0.70 to 0.85 Avg. 0.74	0.70	No. 540
M	MG	MG	MG	G	G	MG	MG		0.72	No. 442
G	1R	MG	MG	G	G	MG	MG		0.79	No. 543
MG	G	MG	MG	G	G	MG	MG		0.78	No. 441
15R	15R	MG	G	G	G	MG	MG		0.70	No. 542
10R	30R	MG	MG	G	G	MG	MG		0.74	No. 443
1R	15R	MG	MG	G	G	MG	MG		0.76	No. 541
MG	10R	MG	MG	G	G	MG	MG		0.76	No. 440
M	MG	MG	MG	G	G	MG	MG	0.80 to 1.00 Avg. 0.90	1.05	No. 348
M	MG	MG	MG	G	G	MG	MG		0.81	No. 248
MG	GY	5R	10R	G	G	MG	MG		0.88	No. 347
G	GY	G	G	G	G	G	MG		0.95	No. 246
GY	GY	MG	MG	G	G	MG	MG*		0.88	No. 346
GY	GY	G	MG	G	G	MG	MG		0.81	No. 245
5R	10R	GY	G	3R	5R	G	G		0.84	No. 345
GY	5R	GY	GY	2R	2R	G	G		0.96	No. 247
M	MG	MG	MG	G	G	MG	MG	1.60 to 1.80	1.75	No. 350
M	M	MG	MG	G	G	MG	MG		1.69	No. 252
M	MG	G	G	G	G	MG	G		1.75	No. 352
M	M	MG	MG	G	G	MG	MG	Avg. 2.76	2.80	No. 397
M	M	MG	MG	G	G	MG	MG		2.72	No. 298
M*	MG*	75SR	75SR	10R	12R	25SR	30R	12 to 14% Cr, cold drawn.		No. 001
M	MG*	35SR	35SR	5SR	5SR	5SR	20SR	12 to 14% Cr, air quenched . . .		No. 002
M	M	MG	MG	M5SY*	M	MG	MG	18% Cr, 8% Ni		No. 003
Gn	Gn	Br	Br	Br	Br	Br	Br	Copper-covered (7.42 oz. per sq. ft.).......		No. 020
10R	5R	30SR	40SR	7R	10R	40SR	50R	Lead-coated (1.48 oz. per sq. ft.)		No. 040

unfabricated wire, fence or barbed wire of the specific wire lot number.

TABLE IV.—REPORT OF INSPECTIONS OF CHAIN LINK SPECIMENS.

Abbreviations and symbols used to designate appearance or states of corrosion: M = metallic; G = gray; Y = yellowed, or rust stained, but not showing actual rough rust of base metal; R = rust of base metal; PHR, PHY = rust or yellowed in pinholes; B, Br, Gn, respectively, signify corroded to a black, brown, or green appearance; D = dark (dirt or soot) to the exclusion of a better observation; MG = intermediate between M and G; GY = predominately gray but showing indication of Y; R+Y = indistinguishable proportions of R and Y; SR = superficial rust.

All 200 series wires are 9 gage. Lead-coated wire, 9 gage. Corrosion-resistant steel, 14 gage.

All 100 series wires are 6 gage. Copper-covered wire 0.128d.

Zinc Coating, oz. per sq. ft of surface, by stripping test	Fence	Sandy Hook, N. J.				Bridgeport, Conn.			
		10.93 yr.	10.92 yr.	11.44 yr.	11.92 yr.	10.43 yr.	10.92 yr.	11.44 yr.	11.93 yr.
0.29	No. E280^a	100R	100R	100R	100R	100R	100R	100R	100R
0.52	No. E281	100R	100R	100R	100R	100R	100R	100R	100R
0.37	No. E282	100R	100R	100R	100R	100R	100R	100R	100R
1.22	No. E185	80R	100R	100R	100R	50R	90R	90R	95R
1.13	No. E285	90R	100R	100R	100R	30R	95R	95R	95R
2.92	No. E290	G	G	G	G	GY	G	G	G
2.09	No. E291	G	G	G	G	GY	GY	G	G
1.60	No. H280^a	70R	70R	70R	100R	50R	80R	90R	90R
1.83	No. H185	30R	70R	70R	70R	30R	50R	65R	90R
1.60	No. H186	10R	30R	40R	50R	10R	60R	75R	75R
1.61	No. H187	5R	35R	35R	50R	5R	20R	30R	35R
1.55	No. H188	80R	100R	90R	100R	70R	90R	95R	90R
1.36	No. H285	50R	80R	80R	90R	50R	80R	80R	80R
1.97	No. H286	15R	80R	80R	90R	30R	40R	50R	50R
1.46	No. H287	50R	90R	90R	90R	60R	80R	85R	80R
1.74	No. H288	10R	40R	70R	90R	10R	20R	40R	50T
1.40	No. H289^b	G	G	GY	1R	GY	GY	G	GY
4.21	No. H290	GY	GY	GY	GY	GY	GY	GY	GY
Lead-coated L050 (1.75 oz. per sq. ft.)		50R+Y	50R+Y	10R	90R+Y	GY	Y	Y	Y
Copper-covered K030 (8.52 oz. per sq. ft.)		Gn	Gn	Gn	Gn	Gn	Gn	Gn	Gn
Corrosion-resistant steel J011		MG	MG	MG	MG	MG	MG	MG	MG

Zinc Coating, oz. per sq. ft. of surface, by stripping test	Fence	State College, Pa.				Lafayette, Ind.		Ithaca, N. Y.		Santa Cruz, Calif.		Davis, Calif.	
		9.40 yr.	9.89 yr.	10.43 yr.	10.90 yr.	10.92 yr.	11.95 yr.	10.82 yr.	12.00 yr.	10.86 yr.	11.85 yr.	10.86 yr.	11.85 yr.
0.29	No. E280[a]	100R	100R	100R	100R	100R	100R	100R	100R	GY	GY	10R	10R
0.52	No. E281	50R	70R	70R	70R	95R	100R	75R	90R	GY	GY	GY	GY
0.37	No. E282	100R	100R	100R	100R	100R	100R	95R	100R	GY	GY	G	G
1.22	No. E185	GY	GY	GY	GY	G	GY	GY	GY	MG	MG	MG	MG
1.13	No. E285	GY	GY	GY	GY	G	GY	G	GY	MG	MG	G	MG
2.92	No. E290	G	G	G	G	MG	G	....	M	MG	MG	MG	MG
2.09	No. E291	G	G	G	G	MG	G	....	MG	MG	MG	MG	MG
1.60	No. H280[a]	G	GY	G	GY	100Y	2R	G	G	MG	MG	MG	MG
1.83	No. H185	GY	GY	GY	GY	G	GY	G	G	MG	MG	MG	MG
1.60	No. H186	G	GY	G	GY	G	GY	G	G	MG	G	MG	MG
1.61	No. H187	G	GY	G	GY	G	GY	G	G	G	G	MG	MG
1.55	No. H188	G	GY	G	GY	G	GY	G	G	MG	MG	MG	MG
1.36	No. H285	G	G	G	GY	G	GY	G	G	G	G	G	MG
1.97	No. H286	G	G	G	GY	G	GY	G	G	MG	MG	MG	MG
1.46	No. H287	G	G	G	GY	G	GY	G	G	MG	MG	MG	MG
1.74	No. H288	G	G	G	GY	G	GY	G	G	MG	MG	G	MG
1.40	No. H289[b]	G	G	G	GY	G	G	M	MG	MG	MG	MG	MG
4.21	No. H290	G	G	G	G	MG	GY		G	MG	MG	MG	MG
Lead-coated L050 (1.75 oz. per sq. ft.)		90R+Y	100R+Y	100R+Y	100R+Y	50PHR	100PHR	5R	10R	25SR	30SR	35SR	35SR
Copper-covered K030 (8.52 oz. per sq. ft.)		Gn	Gn	Gn	Gn	Gn	Gn	B	B	Br	Br	Br	Br
Corrosion-resistant steel J011		M	MG	M	MG	M	M	M	M	MG	MG	MG	MG

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[a] E numbers, coating applied before weaving. H numbers, coating applied after weaving.

[b] While this sample has an H number, its appearance indicates that it was galvanized before weaving.

TABLE V.—REPORT OF INSPECTIONS OF WIRE, STRAND SPECIMENS.

Abbreviations and symbols used to designate appearance or states of corrosion: M = metallic; G = gray; Y = yellowed, or rust-stained, but not showing actual rough rust of base metal; R = rust of base metal; PHR, PHY = rust or yellowed in pinholes; B, Br, Gn, respectively, signify corroded to a black, brown, or green appearance; D = dark (dirt or soot) to the exclusion of a better observation; MG = intermediate between M and G; GY = predominately gray but showing indication of Y; R+Y = indistinguishable proportions of R and Y.

Zinc Coating, oz. per sq. ft. of surface	Strand	Sandy Hook, N. J.				Bridgeport, Conn.				State College, Pa.				Lafayette, Ind.	
		10.43 yr.	10.92 yr.	11.44 yr.	11.92 yr.	10.43 yr.	10.92 yr.	11.44 yr.	11.93 yr.	10.29 yr.	10.77 yr.	11.28 yr.	11.78 yr.	10.92 yr.	11.95 yr.
0.69	No. D345....	15R	30R	50R	50R	5R	45R	50R	70R	G	G	G	G	MG	G
0.88	No. D346....	1R	5R	10R	10R	GY	10R	15R	20R	G	GY	G	GY	G	GY
0.87	No. D347....	5R	20R	25R	30R	5R	10R	15R	20R	G	GY	GY	GY	G	GY
0.93	No. D348....	5R	25R	35R	45R	2R	20R	30R	30R	G	G	G	G	MG	G
1.10	No. D360....	G	G	G	1R	GY	2R	2R	5R	G	G	G	G	MG	G
1.17	No. D361....	1R	1R	1R	2R	GY	GY	GY	GY	G	GY	G	GY	G	GY
1.03	No. D362....	1R	10R	10R	20R	Y	5R	5R	10R	GY	GY	GY	GY	G	GY
1.51	No. D365....	GY	GY	GY	GY	GY	GY	GY	GY	G	GY	G	GY	G	GY
1.39	No. D366....	G	G	G	G	GY	GY	G	GY	G	G	G	G	MG	G
1.32	No. D367....	GY	GY	GY	5R	Y	Y	Y	Y	GY	GY	Y	GY	G	GY
1.71	No. D371....	G	G	G	G	GY	GY	G	GY	G	G	G	G	MG	G
2.47	No. D375....	G	G	G	G	GY	GY	G	GY	G	G	G	G	MG	G
Lead Coating (1.96 oz. per sq. ft.)	No. D045....	100R+Y	100R+Y	100R+Y	100R+Y	95PHR	95R+Y	90R+Y	5R	90R+Y	90R+Y	90R+Y	95R+Y	50PHR	35PHR

Zinc Coating, oz. per sq. ft. of surface	Strand	Ames, Iowa		Manhattan, Kans.		Ithaca, N. Y.		Santa Cruz, Calif.		College Station, Tex.		Davis, Calif.	
		11.04 yr.	11.90 yr.	10.86 yr.	11.90 yr.	10.82 yr.	12.00 yr.	10.86 yr.	11.85 yr.	10.83 yr.	11.83 yr.	10.86 yr.	11.85 yr.
0.69	No. D345....	G	G	G	MG	M	MG	G	G	G	G	G	G
0.88	No. D346....	G	G	G	MG	M	G	MG	MG	G	G	MG	MG
0.87	No. D347....	G	G	MG	GY	G	GY	G	G	G	G	G	G
0.93	No. D348....	G	G	MG	MG	M	MG	MG	G	G	G	G	G
1.10	No. D360....	G	G	MG	MG	M	MG	G	G	G	G	MG	G
1.17	No. D361....	G	G	MG	MG	G	GY	G	G	G	G	MG	G
1.03	No. D362....	G	G	MG	MG	GY	1R	MG	MG	G	G	MG	G
1.51	No. D365....	G	G	MG	GY	M	GY	G	G	G	G	G	G
1.39	No. D366....	G	G	MG	MG	M	MG	G	G	G	G	MG	G
1.32	No. D367....	G	G	MG	MG	GY	GY	MG	MG	G	G	MG	G
1.71	No. D371....	G	G	MG	MG	M	MG	MG	G	G	G	MG	G
2.47	No. D375....	G	G	MG	MG	M	M	MG	G	G	G	G	G
Lead Coating (1.96 oz. per sq. ft.)	No. D045....	17R	25R	50PHY	20PHY	5R	8R	45SR	55SR	80R+Y	75PHY5R	50SR	55SR

PLATE II
PROCEEDINGS, AM. SOC. TESTING MATS.
VOL. 49
REPORT OF COMMITTEE A-5:
WIRE INSPECTION REPORT

REFERENCE INFORMATION

On Unfabricated Wire, Barbed Wire and Fence in the Wire Inspection Report.

The Wire Test Committee responsible for planning and arranging the exposure tests of specimens covered in this report recommends that the following statement be made in all reports relating to the samples of wire and wire products under exposure tests:

> "It is emphasized that the weight of coating ranges shown under each weight group have been arbitrarily chosen and purposely held to close limitations by the Committee and do not necessarily individually represent any manufacturers' commercial product. On the other hand, the entire range of coatings covered by all weight groups as a whole are designed to include a sufficient range of coating to furnish the useful corrosion resistance data desired."

SYSTEM OF NUMBERING SPECIMENS

Zinc coated and uncoated steel specimens (all have 3-digit numbers)..................(c)

When the first digit is.......	5	4	3	2	1
the respective gages are:	14.5	12.5	11	9	6

The second and third digits indicate weight of zinc coating as follows:

	oz. per sq.ft.		oz. per sq.ft.
00-04 (LC)*	uncoated	50-59 (CB)	1.6 to 1.8
05-09 (CB)*	uncoated	60-64 (CB)	1.0 to 1.2
10-14 (CB)	0.20 to 0.30	65-69 (CB)	1.3 to 1.5
15-19 (CB)	0.25 to 0.35	70-74 (CB)	1.6 to 1.8
20-24 (CB)	0.35 to 0.45	75-79 (CB)	2.4 to 2.6
25-29 (CB)	0.45 to 0.55	80-84 (CB)	less than 0.50
30-34 (CB)	0.50 to 0.60	85-89 (CB)	1.2 to 1.5
35-39 (CB)	0.60 to 0.70	90-94 (CB)	2.4 to 3.0
40-44 (CB)	0.70 to 0.85	97-99 (CB)	extra heavy
		95-96 (CB)	chromated after coating
45-49 (CB)	0.80 to 1.00 on farm fence and unfabricated wire. 0.85 to 1.00 on barbed wire. 0.80 to 0.95 on wire strand.		

Specimens of Special Materials:
000-015: uncoated corrosion-resistant steel.
020-030: copper-covered steel.
040-050: lead-coated steel.

Reference Characters

(a)......Wire lot numbers identify wire from a coil or coils of wire supposedly alike.

Wire Lots of Zinc-Coated or Bare Mild Steel	Usually Appear in the Test as shown by ✓				
	Unfab. + Wire	Int. of + Fence	T and B + of Fence	T and B of Fence	Barbed Wire
100 series	✓ (S)	....	....	....	....
200 series	✓ (S)	✓ (S)	✓ (S)	✓ (300)	....
300 series	✓ (S)	✓ (S)	....	✓ (500)	....
400 series	✓ (S)	✓ (S)	....	....	✓ (400)
(s)...... 500 series	✓ (S)	✓ (S)	....	....	....

(S) The specimen numbers of the unfabricated wire or fence are the same as the wire lot numbers.

(300), (400), (500): Specimens of fence numbered in the series 300 have top and bottom wires of the 200 series wire lots; fences numbered in the 500 series have top and bottom wires of the 300 series wire lots. Specimens of barbed wire (numbered in the 400 series) have wire lots of the 400 series but not necessarily of the same identical wire lot numbers.

Par. A. The zinc-coated wire lots table below shows:

(1) All the individual numbered wire lots and the various utilizations of each wire lot in the test.

(2) The results of weight of coating tests on samples cut from each source (unfabricated wire, fence interiors, fence top and bottom wires, and barbed wires).

(b)...... (3) The average coating for each wire lot which is the average of all the figures in the third and following columns in each row.

These average coating figures are the ones entered in other tables of this report. For example, wherever unfabricated wire sample No. 317 or farm fence sample No. 317 are listed, their indicated weights of coating are 0.38 oz. per sq.ft., and not 0.46 and 0.34, respectively.

These wire lot and coating reference data provide an indication of the uniformity of coating on any wire lot.

Par. B. The makeup of fences table below shows:

(1) The lot number of the wire used in the top and bottom line wires of each fence. (The lot number of the wire used in the interior line and stay wires of any fence is the same as the fence number.)

(2) The type of fence, that is, the combination of gages used in its fabrication as explained below:

(d)......				
Type of fence..........................	4	3	2	1
Gage of interior line and stay wires....	14.5	12.5	11	9
Gage of top and bottom line wires......	11	10	9	9

+ ......Abbreviations: Unfab., unfabricated wire; Int., interior line and stay wire; T and B, top and bottom line wires.

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* LC = low copper content wire; CB = copper bearing wire

ZINC-COATED WIRE LOTS: THEIR COATING WEIGHTS AND TEST SPECIMENS IN WHICH THEY ARE USED

(See Par. A and reference characters above for explanations) (Coating weights, oz. per sq.ft.)

Wire Lot (a) (Fence)	(b) Average Coating	Coating Weight Tests on Samples Cut From Unfab. Wire(s)	Coating Weight Tests on Samples Cut From Fence Int.(s)	Barbed Wire Coating	Barbed Wire No.
No. 510(c)	0.29	0.29	0.29		
No. 511	0.24	0.24	0.23		
No. 512	0.27	0.27	0.27		
No. 520	0.36	0.34	0.38		
No. 521	0.38	0.40	0.36		
No. 522	0.44	0.44	0.44		
No. 530	0.61	0.59	0.62		
No. 531	0.60	0.58	0.61		
No. 532	0.49	....	0.49		
No. 540	0.70	0.72	0.68		
No. 541	0.76	0.80	0.72		
No. 542	0.70	0.69	0.71		
No. 543	0.79	0.83	0.74		
No. 551	1.69	1.69	....		
No. 552	2.08	2.08	....		
No. 410(c)	0.30	0.25	0.38	0.27	(410)
No. 411	0.28	0.28	0.28	....	....
No. 412	0.29	0.30	0.30	0.27	(412)
No. 421	0.47	0.49	0.49	0.44	(422)
No. 422	0.35	0.38	0.31	....	....
No. 423	0.31	0.35	0.31	0.28	(420)
No. 430	0.54	0.56	0.52	0.53	(431)
No. 431	0.48	0.49	0.48	0.46	(430)
No. 432	0.57	0.58	0.60	0.53	(432)
No. 433	0.49	....	0.49	....	....
No. 440	0.76	0.72	0.79	....	....
No. 441	0.78	0.77	0.76	0.82	(442)
No. 442	0.72	0.65	0.86	0.64	(441)
No. 443	0.74	0.74	0.78	0.70	(443)
No. 444	0.87	0.87	....	....	....
No. 450	1.50	1.48	....	1.52	(452)
No. 451	1.83	1.71	....	1.95	(451)
No. 495 Cr	Made from unfab. wire 443.				

Wire Lot	Unfab. Wire	Wire Lot	Unfab. Wire
No. 115(c)	0.25	No. 139	0.64
No. 117	0.27	No. 148	0.90
No. 125	0.41	No. 149	0.85
No. 127	0.54	No. 151	1.86
No. 135	0.74	No. 800(6 ga.)	1.35
No. 138	0.67	No. 801(9 ga.)	1.20

Wire Lot (a) (Fence)	(b) Average Coating	Coating Weight Tests on Samples Cut From Unfab. Wire(s)	Fence Int.(s)	T and B of Fence Top	T and B of Fence Bottom	T and B of Fence No.
No. 315(c)	0.25	0.25	0.25	0.25	0.26	(512)
No. 316	0.32	0.32	0.31	0.32	0.33	(510)
No. 317	0.38	0.46	0.34	0.37	0.36	(511)
No. 325	0.44	0.50	0.52	0.37	0.39	(520)
No. 326	0.38	0.40	0.35	....	....	....
No. 327	0.47	0.48	0.44	0.48	0.48	(522)
No. 329	0.54	0.56	....	0.45	0.61	(521)
No. 335	0.61	0.61	0.63	0.59	0.60	(531)
No. 336	0.66	0.73	0.60	....	....	....
No. 337	0.57	0.66	0.59	0.50	0.52	(532)
No. 338	0.69	0.67	0.76	0.67	0.65	(530)
No. 345	0.84	0.83	0.97	0.76	0.79	(541)
No. 346	0.88	0.84	0.84	0.96	0.88	(542)
No. 347	0.88	0.96	1.00	0.78	0.79	(543)
No. 348	1.05	1.04	1.07	1.05	1.06	(540)
No. 350	1.75	1.73	1.76	....	....	....
No. 351	1.65	1.65	....	....	....	....
No. 352	1.75	1.82	1.68	....	....	....
No. 397	2.80	2.80	2.79	....	....	....

Wire Lot (a) (Fence)	(b) Average Coating	Unfab. Wire(s)	Fence(s) T-B Top	Fence(s) T-B Bottom	T and B of Fence Top	T and B of Fence Bottom	T and B of Fence No.
No. 215(c)	0.28	0.28	0.25	0.25	0.33	0.29	(315)
No. 216	0.28	0.31	0.30	0.31	0.27	0.29	(316)
No. 217	0.36	0.29	....	....	0.40	0.39	(317)
No. 225	0.45	0.45	0.49	0.44	0.43	0.47	(327)
No. 226	0.45	0.46	....	....	0.45	0.45	(326)
No. 227	0.51	0.59	0.48	0.49	....	....	
No. 228	0.50	0.49	0.48	0.48	0.50	0.53	(325)
No. 235	0.67	0.82	0.60	0.62	0.68	0.64	(337)
No. 236	0.68	0.66	0.68	0.73	0.69	0.65	(338)
No. 237	0.63	0.72	0.67	0.55	0.58	0.61	(335)
No. 238	0.60	0.60	0.59	0.61	0.59	0.61	(336)
No. 239	0.65	0.65	....	....	....	....	....
No. 245	0.81	0.80	0.83	0.78	0.81	0.81	(346)
No. 246	0.95	0.97	0.94	0.98	0.89	0.95	(347)
No. 247	0.96	0.94	0.95	1.00	1.01	0.91	(345)
No. 248	0.81	0.66	0.92	0.68	0.91	0.89	(348)
No. 250	1.76	1.76	....	....	....	....	....
No. 251	1.86	1.68	....	....	1.99	1.91	(352)
No. 252	1.69	1.67	1.85	1.57	....	....	(350)
No. 282	0.37	0.37	....	....	....	....	....
No. 296 Cr	Made from unfab. wire 245.						
No. 298	2.72	2.78	2.71	2.74	2.71	2.67	(397)
No. 299	3.00	3.00	....	....	....	....	....

MAKEUP OF FENCES

(See Par. B and reference characters above)

Int. Lot (Fence)	Type (d)	T-B Lot	Int. Lot (Fence)	Type (d)	T-B Lot
ZINC-COATED FENCES					
No. 510	4	No. 316	No. 410	3	....
No. 511	4	No. 317	No. 411	3	....
No. 512	4	No. 315	No. 412	3	....
No. 520	4	No. 325	No. 421	3	....
No. 521	4	No. 329	No. 422	3	....
No. 522	4	No. 327	No. 423	3	....
No. 530	4	No. 338	No. 430	3	....
No. 531	4	No. 335	No. 431	3	....
No. 532	4	No. 337	No. 432	3	....
No 540	4	No. 348	No. 433	3	....
No. 541	4	No. 345	No. 440	3	....
No. 542	4	No. 346	No. 441	3	....
No. 543	4	No. 347	No. 442	3	....
			No. 443	3	....
No. 315	2	No. 215			
No. 316	2	No. 216	No. 215	1	No. 215
No. 317	2	No. 217	No. 216	1	No. 216
No. 325	2	No. 228	No. 225	1	No. 225
No. 326	2	No. 226	No. 227	1	No. 227
No. 327	2	No. 225	No. 228	1	No. 228
No. 335	2	No. 237	No. 235	1	No. 235
No. 336	2	No. 238	No. 236	1	No. 236
No. 337	2	No. 235	No. 237	1	No. 237
No. 338	2	No. 236	No. 238	1	No. 238
No. 345	2	No. 247	No. 245	1	No. 245
No. 346	2	No. 245	No. 246	1	No. 246
No. 347	2	No. 246	No. 247	1	No. 247
No. 348	2	No. 248	No. 248	1	No. 248
No. 350	2	No. 252	No. 252	1	No. 252
No. 352	2	No. 251	No. 298	1	No. 298
No. 397	2	No. 298			
BARE-STEEL FENCES					
No. 505	4	No. 306	No. 305	2	No. 206
No. 506	4	No. 305	No. 306	2	No. 207
No. 405	3	....	No. 205	1	No. 205
No. 406	3	....	No. 206	1	No. 206

Coppered-covered steel fence No. 020	Int. No. 021	2	No. 022
Lead-coated steel fence No. 040	Int. No. 041	1	No. 041

UNCOATED CORROSION-RESISTANT STEEL FENCES

No. 001 (T - B Lot No. 001) Gages: Int. 12 ; T - B 12
No. 002 (T - B Lot No. 002) Gages: Int. 12.5; T - B 12.5
No. 003 (T - B Lot No. —) Gages: Int. 15 ; T - B 13

TABLE VI.—BREAKING LOADS AND ELONGATION OF UNFABRICATED WIRE SPECIMENS.

Wire Lot	Breaking Load, lb.	Elongation in 10 in., per cent	Wire Lot	Breaking Load, lb.	Elongation in 10 in., per cent
TESTS ON UNCOATED SPECIMENS EXPOSED 10.82 YR. AT ITHACA, N. Y.					
No. 501	355	0.7	No. 305	945	3.5
No. 506	355	0.5	No. 306	660	15.7
No. 507	390	0.4	No. 200	920	13.3
No. 400	410	13.1	No. 202	1520	2.9
No. 401	365	11.5	No. 205	995	13.3
No. 405	390	11.5	No. 206	1310	7.8
No. 406	400	12.2	No. 101	2175	4.3
No. 300	670	14.8	No. 102	1885	10.0
No. 302	915	3.3	No. 105	2550	3.5
			No. 106	2245	1.9
TESTS ON UNCOATED SPECIMENS EXPOSED 10.92 YR. AT LAFAYETTE, IND.					
No. 501	310	0.4	No. 305	845	3.1
No. 506	300	0.2	No. 306	600	14.2
No. 507	345	0.2	No. 200	845	11.5
No. 400	375	11.1	No. 202	....	....
No. 401	320	9.4	No. 205	955	11.1
No. 405	360	8.6	No. 206	1215	6.0
No. 406	360	10.7	No. 101	2070	3.8
No. 300	625	13.5	No. 102	1805	9.5
No 302	825	2.3	No. 105	2410	2.5
			No. 106	2180	1.9
TESTS ON UNCOATED SPECIMENS EXPOSED 11.04 YR. AT AMES, IOWA					
No. 501	370	0.5	No. 305	920	3.8
No. 506	360	0.3	No. 306	635	14.3
No. 507	410	0.7	No. 200	905	11.3
No. 400	410	15.0	No. 202	....	....
No. 401	365	13.3	No. 205	1045	10.2
No. 405	380	12.5	No. 206	1295	7.1
No. 406	405	13.1	No. 101	2150	3.7
No. 300	660	15.0	No. 102	1885	8.8
No. 302	915	3.1	No. 105	2510	3.5
			No. 106	2230	2.2
TESTS ON UNCOATED SPECIMENS EXPOSED 10.86 YR. AT SANTA CRUZ, CALIF.					
No. 501	325	0.4	No. 305	935	1.8
No. 506	350	0.5	No. 306	615	11.6
No. 507	355	0.1	No. 200	900	11.0
No. 400	385	8.6	No. 202	1510	3.5
No. 401	370	6.1	No. 205	1005	11.2
No. 405	395	8.1	No. 206	1320	5.9
No. 406	400	9.2	No. 101	2205	4.1
No. 300	665	13.2	No. 102	1870	10.4
No. 302	905	3.0	No. 105	2535	3.0
			No. 106	2180	1.9
TESTS ON UNCOATED SPECIMENS EXPOSED 10.83 YR. AT COLLEGE STATION, TEXAS					
No. 501	380	0.4	No. 305	955	4.5
No. 506	395	0.3	No. 306	650	14.8
No. 507	440	0.3	No. 200	925	12.3
No. 400	435	12.7	No. 202	1540	3.8
No. 401	385	9.3	No. 205	1075	11.7
No. 405	435	12.0	No. 206	1355	7.7
No. 406	430	13.9	No. 101	2240	3.5
No. 300	685	15.3	No. 102	1915	9.7
No. 302	890	3.7	No. 105	2705	3.7
			No. 106	2225	2.6
TESTS ON UNCOATED SPECIMENS EXPOSED 10.86 YR. AT DAVIS, CALIF.					
No. 501	425	0.8	No. 305	1005	6.3
No. 506	420	0.3	No. 306	675	15.9
No. 507	485	0.3	No. 200	950	13.1
No. 400	460	16.5	No. 202	1485	3.9
No. 401	415	15.2	No. 205	1040	12.9
No. 405	435	15.8	No. 206	1850	8.7
No. 406	435	16.4	No. 101	2190	3.1
No. 300	705	17.6	No. 102	1905	9.6
No. 302	955	4.8	No. 105	2685	3.8
			No. 106	2310	2.3

TABLE VI.—*Continued.*

Wire Lot	Breaking Load, lb.	Elongation in 10 in., per cent	Wire Lot	Breaking Load, lb.	Elongation in 10 lb., per cent
TESTS ON UNCOATED SPECIMENS EXPOSED 10.86 YR. AT MANHATTAN, KANS.					
No. 501	465	0.7	No. 305	1070	6.7
No. 506	490	0.4	No. 306	710	17.7
No. 507	575	0.6	No. 200	1020	14.7
No. 400	475	16.5	No. 202	....	....
No. 401	445	15.0	No. 205	1100	13.1
No. 405	485	15.7	No. 206	1430	9.0
No. 406	470	17.7	No. 101	2290	4.2
No. 300	750	18.6	No. 102	1980	10.9
No. 302	1035	5.6	No. 105	2755	3.0
			No. 106	2395	2.5
TESTS ON UNCOATED SPECIMENS EXPOSED 10.36 YR. AT BRIDGEPORT, CONN.					
No. 501	270	0.3	No. 101	1960	3.3
No. 506	280	0.3	No. 102	1755	10.0
No. 507	310	0.1	No. 105	2385	2.3
			No. 106	2140	1.8
TESTS ON UNCOATED SPECIMENS EXPOSED 11.43 YR. AT SANDY HOOK, N. J.					
No. 400	220	4.4	No. 405	215	2.9
No. 401	175	1.7	No. 406	255	5.9
TESTS ON UNCOATED SPECIMENS EXPOSED 10.47 YR. AT PITTSBURGH, PA.					
No. 300	270	6.7	No. 305	390	0.5
No. 302	280	0.3	No. 306	295	6.9
TESTS ON UNCOATED SPECIMENS EXPOSED 11.46 YR. AT PITTSBURGH, PA.					
No. 200	315	8.4	No. 205	485	4.7
No. 202	715	1.3	No. 206	690	3.0

ZINC-COATED UNFABRICATED WIRE SPECIMENS

Wire Lot	Exposure to 1R, yr.	Breaking Load, lb.	Elongation in 10 in., per cent	Wire Lot	Exposure to 1 R, yr.	Breaking Load, lb.	Elongation in 10 in., per cent
TESTS ON ZINC-COATED SPECIMENS EXPOSED 10.36 YR. AT BRIDGEBPORT, CONN.							
No. 510	2.5	320	0.3	No. 421	2.7	375	11.0
No. 511	1.8	170	8.5	No. 422	2.7	4.5	11.0
No. 512	1.6	200	3.4	No. 423	2.5	325	14.3
No. 520	2.5	215	11.0	No. 430	4.8	670	0.9
No. 521	3.4	195	9.2	No. 431	3.5	685	1.3
No. 522	3.4	340	0.2	No. 432	5.4	430	4.3
No. 315	1.7	755	8.2	No. 325	3.9	655	14.5
No. 316	2.5	955	3.8	No. 326	2.9	555	14.5
No. 317	2.8	665	11.8	No. 327	3.9	965	2.8
No. 282	2.8	1145	10.1	No. 329	3.8	615	11.8
TESTS ON ZINC-COATED SPECIMENS EXPOSED 11.4 YR. AT BRIDGEPORT, CONN.							
No. 410	1.8	420	8.8	No. 530	5.4	215	5.6
No. 411	2.3	490	1.4	No. 531	4.7	325	0.3
No. 412	2.5	630	1.4	No. 540	6.2	215	2.8
No. 440	4.8	495	8.8	No. 541	4.9	365	8.7
No. 441	5.9	405	11.7	No. 542	5.5	325	0.3
No. 442	6.3	365	9.4	No. 543	5.9	205	3.1
No. 443	5.8	615	1.4	No. 335	5.4	880	3.7
No. 444	5.6	460	11.6	No. 336	5.4	655	14.0
No. 495	5.9	615	0.9	No. 337	5.4	725	11.9
				No. 338	6.7	870	1.1
No. 225	3.9	1455	4.1	No. 227	4.4	1435	5.0
No. 226	3.9	1045	16.5	No. 228	3.8	995	14.0
TESTS ON ZINC-COATED SPECIMENS EXPOSED 10.35 YR. AT SANDY HOOK, N. J.							
No. 410	1.80	335	4.8	No. 510	1.75	200	0.2
No. 411	1.85	385	0.8	No. 511	1.75	100	1.6
No. 412	2.5	540	0.7	No. 512	1.55	120	0.7
No. 421	2.8	305	7.0	No. 520	2.7	155	3.7
No. 422	2.9	365	9.3	No. 521	2.9	120	2.1
No. 423	2.75	260	8.0	No. 522	2.9	215	0.2
No. 430	4.4	535	0.3	No. 530	2.9	180	2.3
No. 431	3.7	610	1.1	No. 531	4.7	265	0.2
No. 432	6.5	415	4.6	No. 282	2.8	1045	8.7

TABLE VI.—*Continued.*

Wire Lot	Exposure to 1 R, yr.	Breaking Load, lb.	Elongation in 10 in., per cent	Wire Lot	Exposure to 1 R, yr.	Breaking Load, lb.	Elongation in 10 in., per cent
TESTS ON ZINC-COATED SPECIMENS EXPOSED 11.40 YR. AT SANDY HOOK, N. J.							
No. 440	4.7	390	6.2	No 540	5.9	175	1.5
No. 441	6.5	360	6.1	No. 541	5.4	165	1.2
No. 442	7.4	350	5.6	No. 542	5.5	230	0.5
No. 443	5.9	545	0.8	No. 543	5.9	165	1.7
No. 444	5.7	435	7.5	No. 335	4.9	780	1.6
No. 495	5.9	575	0.7	No. 336	4.8	550	9.8
No. 235	5.5	1155	10.2	No. 337	4.8	675	8.5
No. 236	7.7	1280	2.0	No. 338	7.9	865	1.0
No. 237	4.4	1290	3.2	No. 345	5.9	665	8.4
No. 238	4.8	1300	3.0	No. 346	6.5	870	2.9
No. 239	5.5	975	13.9	No. 347	7.8	720	6.5
No. 325	3.8	590	11.5	No. 348	...	930	1.0
No. 326	3.85	510	10.8	No. 315	1.6	590	6.2
No. 327	3.8	845	0.9	No. 316	2.7	810	1.2
No. 329	3.8	525	9.7	No. 317	3.75	585	8.7
TESTS ON ZINC-COATED SPECIMENS EXPOSED 11.28 YR. AT STATE COLLEGE, PA.							
No. 510	5.7	335	0.3	No. 410	4.5	440	9.7
No. 511	4.7	175	10.2	No. 411	5.5	500	4.0
No. 512	4.5	190	6.1	No. 412	5.7	640	1.0
No. 520	6.3	220	12.1	No. 421	5.8	385	12.5
No. 521	6.8	210	11.3	No. 422	6.8	420	13.8
No. 522	7.5	375	0.3	No. 423	5.8	320	14.8
				No. 282	6.7	1205	9.3
TESTS ON ZINC-COATED SPECIMENS EXPOSED 10.47 YR. AT BRUNOT ISLAND (PITTSBURGH, PA.)							
No. 246	2.90	765	7.7	No. 351	2.90	550	4.5
No. 250	3.90	970	4.8	No. 352	3.90	775	0.1
No. 251	3.90	1345	0.7	No. 397	7.50	670	0.2
No. 252	4.50	775	6.5	No. 800	3.90	2040	4.5
No. 350	5.10	390	6.2	No. 801	3.50	995	1.9
TESTS ON ZINC-COATED SPECIMENS EXPOSED 11.46 YR. AT BRUNOT ISLAND (PITTSBURGH, PA.)							
No. 148	2.75	1930	3.3	No. 248	2.1	800	0.7
No. 149	2.75	1455	12.0	No. 296	2.5	930	2.0
No. 151	3.90	2455	0.7	No. 298	7.7	1155	1.9
No. 215	0.60	550	8.6	No. 299	7.0	1385	0.7
No. 216	1.30	850	2.4	No. 315	0.45	240	3.2
No. 217	1.05	685	5.9	No. 316	1.20	365	0.8
No. 225	1.90	930	1.4	No. 325	1.75	300	7.9
No. 226	1.90	710	10.8	No. 326	1.40	60	1.2
No. 227	2.50	880	2.1	No. 327	1.80	345	0.5
No. 228	1.60	665	11.1	No. 329	1.85	225	5.4
No. 235	2.6	755	6.0	No. 335	1.6	330	0.3
No. 236	2.0	795	0.9	No. 336	2.75	250	4.1
No. 237	1.8	860	1.3	No. 337	2.5	255	3.4
No. 238	2.5	935	1.9	No. 338	2.0	335	0.3
No. 239	2.6	695	11.0	No. 345	2.7	295	2.1
No. 245	2.4	830	1.5	No. 346	2.55	320	0.5
No. 246	2.9	640	8.2	No. 347	2.65	270	2.9
No. 247	2.9	935	2.8	No. 348	3.2	335	0.3
				No. 397	7.5	615	0.6
TESTS ON LEAD-COATED SPECIMENS EXPOSED 10.47 YR. AT BRUNOT ISLAND (PITTSBURGH, PA.)							
No. 040	0.9	1620	5.2	No. 042	0.9	610	3.6
No. 041	0.9	955	5.6	No. 043	0.9	235	1.1

REPORT OF COMMITTEE A-6
ON
MAGNETIC PROPERTIES*

Committee A-6 on Magnetic Properties has had one meeting since the previous report, at Detroit, Mich., on June 21, 1948.

During the year, the committee has suffered the loss of three of its most active and valued members; Mr. J. A. Ashworth by death and P. H. Dike and C. W. Rust by retirement. They will all be greatly missed. Mr. Ashworth was chairman of Subcommittee V on Correlation of Magnetic Testing Equipment and Methods, having initiated the work of this subcommittee some time ago. Mr. Dike had been Vice-Chairman of Committee A-6 since 1936 when that office was established. He was also chairman of Subcommittee I on Nomenclature and Definitions. Mr. Rust was one of the oldest members in years of service and has contributed much to the work of the committee. Mr. Thomas Spooner has relinquished the chairmanship of the committee which he has held continuously for a period of twenty-three years. His capable and wise guidance has contributed greatly to the accomplishments of Committee A-6.

The following have been appointed to membership during the year: A. C. Beiler of the Westinghouse Electric Corp., D. C. Dieterly of the Armco Steel Corp., R. E. Watson of the Leeds & Northrup Co., V. E. Legg of the Bell Telephone Laboratories, and C. J. Witsberger of the Pennsylvania Transformer Co.

Since the Annual Meeting, the subcommittees have been completely reorganized as follows:

I. Nomenclature and Definitions, G. H. Cole, chairman,
II. Methods of Sampling and Tests, J. W. Hale, chairman,
III. Editorial, R. C. Taylor, chairman, and
IV. Accuracy of Test Methods, A. C. Beiler, chairman.

The chairmen of the subcommittees together with the officers of the main committee constitute the Advisory Committee.

The major project during the year has been an extensive revision by Subcommittee III of the Standard Methods of Testing Magnetic Materials (A 34 - 48), consisting mainly of a regrouping under the general designation A 34 using the serial numbers A 340 to A 349 to designate the various sections. Methods A 34 - 48 were a voluminous document including 85 sections and 15 figures in a total of 36 pages. A minor revision in the methods, such as adding a new section, resulted in a large number of changes in internal references, etc. To eliminate this, the present sections in Methods A 34 have been regrouped under five designations: namely, A 34, A 341, A 342, A 343, and A 344. This has also involved a certain amount of editorial revision in the interests of uniformity. Also, it is proposed to redesignate the present Standard Definitions of Terms with Symbols, Relating to Magnetic Testing (A 127 - 48) as A 340 and to adopt as standard the present Tentative Specifications for Flat-

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

Rolled Electrical Steel (A 310 - 47 T) with the new designation A 345.

It should be noted that the revision and regrouping of Method A 34 will in no way affect current reference to these methods as may now obtain on drawings or otherwise, for the new A 34 will, wherever A 34 is cited, still specify the use of the same methods that have now been regrouped under other designations.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the Tentative Specifications for Flat-Rolled Electrical Steel (A 310 - 47 T) be approved for reference to letter ballot of the Society for adoption as standard without revision and that it be redesignated as A 345 - 49.

REVISIONS OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions in Methods A 34 which consist of a division and revision of these methods into the following five standards as explained in the following outline. The committee accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society for immediate adoption.

Standard Methods of:

Testing Magnetic Materials (A 34 - 48), as appended hereto,[1]

Test for Normal Induction and Hysteresis of Magnetic Materials (A 341), as appended hereto,[1]

Test for Core Loss and Permeability of Magnetic Materials by Alternating Current Procedures (A 343), as appended hereto,[1]

Test for Permeability of Feebly Magnetic Materials (A 342), with the following revisions:

Sections 1 and 2.—Reword the present Sections 39 and 80 of Methods A 34 - 48 to read as follows:

1. *Scope.*—These methods of test cover four procedures for determining the permeability of materials having a permeability not exceeding 2.0.

2. *Choice of Methods.*—(*a*) Methods 1, 2, and 3 are alternative methods for materials with permeabilities between 1.0 and 2.0.

NOTE.—These methods can be used with smaller dimension-ratio test specimens when used for comparing similar specimens for quality control purposes. The absolute values may, of course, not meet the 2 per cent accuracy limits.

(*b*) Method 4 is suitable for measurement of permeability of paramagnetic materials having a permeability less than 1.05.

Method No. 1.—New Sections 3 to 7, inclusive, consisting of the present Sections 40 to 44, inclusive, of Methods A 34 - 48. The note in Section 44 will be omitted since it is covered by the note in the new Section 2 (*a*).

Method No. 2.—New Sections 8 to 12, inclusive, consisting of the present Sections 45 to 49, inclusive, of Methods A 34 - 48. The note in Section 49 will be omitted since it is covered by the note in the new Section 2 (*a*).

Method No. 3.—New Sections 13 to 17, inclusive, consisting of the present Sections 50 to 54, inclusive, of Methods A 34 - 48.

Method No. 4.—New Sections 18 to 22, inclusive, consisting of the present Sections 81 to 85, inclusive, of Methods A 34 - 48.

Standard Methods of Test for Electrical and Mechanical Properties of Magnetic Materials (A 344), with revisions as follows:

Section 1.—Add the following as a new Section 1:

1. *Scope.*—These methods cover test procedures for electrical resistivity, interlamination resistance, lamination factor, and ductility.

The details of the four procedures are given as follows:

Electrical Resistivity.—New Sections 2 to 7, inclusive, consisting of the present Sections 64 to 69, inclusive, of Methods A 34 - 48.

Section 8.—Add the following new material on "Accuracy" as Section 8:

8. *Accuracy.*—Accuracy of the method for measuring resistivity of magnetic materials of usual surface finish is estimated to be within 2 per cent.

Interlamination Resistance.—New Sections 9 to 13, inclusive, consisting of the present Sections 55 to 58, inclusive of Methods A 34 - 48. The new Section 12 will consist of Paragraphs (*a*) to (*d*) identical with Paragraphs of the same letter of the present Section 58 of Methods A 34 - 48. The new Section 13 will contain the material of the old Section 58 (*e*) of Methods A 34 - 48.

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[1] These revised methods were accepted by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 1.

Lamination Factor.—New Sections 14 to 18, inclusive, consisting of the present Sections 59 to 63, inclusive, of Methods A 34 - 48.

Ductility, Cup Test.—New Sections 19 to 23, inclusive, consisting of the present Sections 70 to **74**, of Methods A 34 - 48.

Ductility, Bend Test.—New Sections 24 to 28, inclusive, consisting of the present Sections 75 to 79, inclusive, of Methods A 34 - 48.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

This report has been submitted to letter ballot of the committee which consists of 33 members; 22 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

R. L. SANFORD,
Chairman.

J. P. BARTON,
Secretary.

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[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

REPORT OF COMMITTEE A-7

ON

MALLEABLE IRON CASTINGS*

Committee A-7 on Malleable Iron Castings held one meeting during the current year on June 23, 1948, during the Annual Meeting of the Society in Detroit, Mich. Members-at-large elected at that meeting to serve on the Advisory Committee were George E. Bean, J. J. Kanter, H. A. Schwartz, F. G. Steinebach.

During the year there was one removal from the list of members. Due to retirement from active business, Mr. Arthur Jameson resigned from A.S.T.M. and Committee A-7. Mr. Jameson has rendered valuable service over a period of many years and his resignation was received with deep regret.

At the present time the committee consists of 59 members of whom 55 are voting members; 29 are classified as producers, 16 as consumers, and 14 as general interest members.

Committee A-7 is continuing its general interest in the project of working out some arrangement with the National Bureau of Standards by which a white iron sample will be added to the Bureau's list of standard samples. Some supplementary consideration has been given to the possible development of standard methods of analysis which have special application to work with white iron.

TENTATIVES CONTINUED WITHOUT REVISION

It was originally recommended that the Tentative Specifications for Pearlitic Malleable Iron Castings (A 220 - 48 T) and the Tentative Specifications for Malleable Iron Flanges, Pipe Fittings, and Valve Parts (A 277 - 44 T) be adopted as standard. Due to the number of objections raised on the adoption of these tentatives as standard, it was decided to continue them in their present status for the coming year, during which time they are to be given further consideration in the light of the latest information.

This report has been submitted to letter ballot of the committee, which consists of 59 members; 52 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

W. A. KENNEDY,
Chairman.

J. H. LANSING,
Secretary.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27-July 1, 1949.

REPORT OF COMMITTEE A-9
ON
FERRO-ALLOYS*

Committee A-9 on Ferro-Alloys held a meeting on March 3, 1948, and plans to meet in Atlantic City, N. J., on June 29, 1949.

A Task Group of Committee A-9 is scheduled to meet in Atlantic City with representatives of Committee B-9 on Metal Powders to discuss the scope of Committee A-9's activities in so far as they concern powdered metals for metallurgical use.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Specifications (E. A. Lucas, chairman) has prepared Tentative Specifications for Ferrotitanium and for Ferroboron which have been distributed for letter ballot to the committee. It has revised the Standard Specifications for Molybdenum Salts and Compounds (A 146 – 39) to include molybdenum oxide in bags or cans and molybdic oxide briquets and the specifications will also be modified by incorporating therein the material now in the Tentative Method for Sampling Molybdenum Salts and Compounds for Metallurgical Use (E 66 – 34 T) at the same time reverting the specifications to tentative. All three specifications, when completed, will be submitted to the Administrative Committee on Standards.[1]

Subcommittee II on Sampling (W. C. Bowden, Jr., chairman) plans to meet with representatives of Committee E-3 on Chemical Analysis of Metals to prepare methods for sampling ferrotitanium and ferroboron.

This report has been submitted to letter ballot of the committee, which consists of 27 members; 25 members returned their ballots, of whom 24 have voted affirmatively and none negatively.

Respectfully submitted on behalf of the committee,

W. C. BOWDEN, JR.
Chairman.

G. F. COMSTOCK,
Secretary.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] See Editorial Note below.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee A-9 presented to the Society through the Administrative Committee on Standards the following recommendations:

New Tentative Specifications for:
Ferroboron (A 323 – 49 T), and
Ferrotitanium (A 324 – 49 T).

Revision and Reversion to Tentative of Standard Specifications for:
Molybdenum Salts and Compounds (A 146 – 39).

These recommendations were accepted by the Standards Committee on August 19, 1949, and the specifications appear in the 1949 Book of A.S.T.M. Standards, Part 1.

REPORT OF COMMITTEE A-10
ON
IRON-CHROMIUM, IRON-CHROMIUM-NICKEL, AND RELATED ALLOYS[*]

Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel, and Related Alloys held meetings at Detroit, Mich., on June 23, 1948, during the Annual Meeting of the Society, and on March 2, 1949, at Chicago, Ill.

Some changes in representation on the committee occurred during the past year. The present committee consists of 90 members, of whom 41 are classified as producers, 35 as consumers, and 14 as general interest members.

RECOMMENDATION ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

On November 15, 1948, the Administrative Committee on Standards accepted the joint recommendation of Committee A-1 on Steel and Committee A-10 that the Specifications for Seamless and Welded Austenitic Stainless Steel Pipe be approved for publication as tentative. The new tentative specifications appear in the 1948 Supplement to Book of A.S.T.M. Standards, Part I-A, bearing the designation A 312 - 48 T.

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revision of the following standards and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society.

Standard Specifications for Corrosion-Resisting Chromium Steel Plate, Sheet, and Strip (**A 176 - 44**):[1]

Section 7 (b).—Change to read as follows:

> (*b*) The yield strength shall be determined by the offset method as described in Standard Methods of Tension Testing of Metallic Materials (A.S.T.M. Designation: E 8). The limiting permanent offset shall be 0.2 per cent of the gage length of the specimen. An alternate method of determining yield strength may be used based on a total extension under load of 0.5 per cent.

Table II.—Delete footnote *a*.

Standard Specifications for Corrosion-Resisting Chromium and Chromium-Nickel Steel Plate, Sheet, and Strip for Fusion Welded Unfired Pressure Vessels (**A 240 - 44**):[1]

Table I.—Add one new grade "O" with the following requirements:

	Grade O
Type Number	405[a]
Carbon, max., per cent	0.08
Manganese, max., per cent	1.00
Phosphorus, max., per cent	0.040
Sulfur, max., per cent	0.040
Silicon, max., per cent	1.00
Chromium, per cent	11.50 to 13.50
Nickel, per cent	0.60 max.

[a] Aluminum 0.10 to 0.30 per cent.

Table II.—For grade A, change the tensile strength from "70,000 min., psi." to "65,000 min., psi."; the yield strength from "35,000 min., psi." to "30,000 min., psi."; the elongation in 2 in. from "25 min., per cent" to "22 min., per cent."

Add one new grade with the following requirements:

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[*] Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] 1946 Book of A.S.T.M. Standards, Part I-A.

	Grade O
Type Number	405
Tensile strength, min., psi	60 000
Yield strength, min., psi	25 000
Elongation in 2 in., min., per cent	25.0
Brinell Hardness, max.	202
Rockwell Hardness, max.	B88
Cold bend, deg.	180

Footnote a.—Change to read: "Yield strength shall be determined by the offset method at 0.2 per cent limiting permanent set in accordance with Standard Methods of Tension Testing of Metallic Materials (A.S.T.M. Designation: E 8 – 46). An alternate method of determining yield strength may be used based on a total extension under load of 0.5 per cent.

TABLE I.—CHEMICAL REQUIREMENTS.

Type	Chemical Composition, per cent							
	C	Mn, max.	Si, max.	P, max.	S, max.	Cr	Ni	Other Elements
302	Over 0.08-0.20	2.00	1.00	0.040	0.030	17.00-19.00	8.00-10.00	....
303	0.15 max.	2.00	1.00	....	....	17.00-19.00	8.00-10.00	P, S, Se, min. 0.07; Zr Mo, max. 0.60
304	0.08 max.	2.00	1.00	0.040	0.030	18.00-20.00	8.00-11.00	....
316	0.10 max.	2.00	1.00	0.040	0.030	16.00-18.00	10.00-14.00	Mo 2.00/3.00
321	0.08 max.	2.00	1.00	0.040	0.030	17.00-19.00	8.00-11.00	Ti 5xC min.
347	0.08 max.	2.00	1.00	0.040	0.030	17.00-19.00	9.00-12.00	Cb 10xC min.
410	0.15 max.	1.00	1.00	0.040	0.030	11.50-13.50	....	....
416	0.15 max.	1.25	1.00	...	....	12.00-14.00	....	P, S, Se min. 0.07, Zr, Mo, max. 0.60
420	Over 0.15	1.00	1.00	0.040	0.030	12.00-14.00	....	....
430	0.12 max.	1.00	1.00	0.040	0.030	14.00-18.00	....	....
440	(a)	1.00	1.00	0.040	0.030	16.00-18.00	....	Mo 0.75 max.

TABLE II.—PHYSICAL TEST REQUIREMENTS.

Diameter or Thickness, in.	Yield Strength, 0.2 per cent offset, min., psi.	Tensile Strength, min., psi.	Elongation in Four Times the Diameter, min., per cent	Reduction of Area, min., per cent	Brinell Hardness, max.
Up to ¾ in., incl.	100 000	125 000	12	35	...
Over ¾ to 1 in., incl.	80 000	115 000	15	35	...
Over 1 to 1¼ in., incl.	65 000	105 000	20	35	...
Over 1¼ in. to 1½ in., incl.	50 000	100 000	28	45	...
Over 1½ in. to 3 in., incl.	45 000	95 000	28	45	...
Over 3 in.	35 000	80 000	28	45	...
Under Heat Treated Types 410 and 416, change to:					
All sizes	90 000	120 000	13	45	302

REVISIONS OF TENTATIVES

The committee recommends that the following tentatives be revised as indicated:

Tentative Specifications for Corrosion-Resistant Iron-Chromium and Iron-Chromium-Nickel Alloy Castings for General Application **(A 296 – 46 T)**:[1]

Table II.—Make the following changes:

Grades 1, 3, 4, 5, 6, and 11.—Change chromium content from "18.0 to 22.0 per cent" to "18.0 to 21.0 per cent."

Grade 2.—Change chromium content from "20.0 to 24.0 per cent" to "20.0 to 23.0 per cent."

Grade 6.—Insert a maximum requirement of "0.05" for phosphorous and sulfur, retaining the reference to footnote *a* for these items

Section 14 (a). —Change to read as follows:

14. (*a*) Critical surfaces of all castings intended for corrosion-resistant service shall be cleaned as agreed upon by the manufacturer and the purchaser. Cleaning may be accomplished by blasting with clean sand or metallic corrosion resisting shot or by other approved methods.

Tentative Specifications for Heat-Resistant Iron-Chromium and Iron-Chromium-Nickel Alloys for General Application **(A 297 – 46 T)**:[1]

Table I.—Make the following changes:

Grade 1.—Change the carbon content from "0.20 to 0.35 per cent" to "0.20 to 0.40 per cent" and the chromium content from "18.0 to 22.0 per cent" to "18.0 to 23.0 per cent."

Grade 2.—Change the carbon content from "0.20 to 0.45 per cent" to "0.20 to 0.50 per cent," and the chromium content from "23.0 to 27.0 per cent" to "24.0 to 28.0 per cent."

Grade 3.—Change the carbon content from "0.20 to 0.45 per cent" to "0.20 to 0.50 per cent."

Grade 4.—Change the carbon content from "0.20 to 0.45 per cent" to "0.20 to 0.60 per cent"; the chromium content from "23.0 to 27.0 per cent" to "24.0 to 28.0 per cent" and the nickel content from "19.0 to 22.0 per cent" to "18.0 to 22.0 per cent."

Tentative Specifications for Hot-Rolled and Cold-Finished Corrosion-Resisting Steel Bars (**A 276 – 44 T**):[1]

Table I.—Revise to read as given in the accompanying Table I, deleting the present footnotes *b*, *d*, *e*, and *f*.

Table II.—Change the requirements for cold-finished types 302, 303 (selenium bearing), 304, 316, 321, and 347 to read as given in the accompanying Table II.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Classification of Data: (F. P. Peters, chairman) held meetings on June 22 and November 1, 1948, the latter exclusively in connection with work on the revision of the wrought steel data compilation. At the June meeting it was reported that the compilation of data on cast steels, which had been in A.S.T.M. Headquarter's hands for some time awaiting completion of wrought steel data so that the two could be published simultaneously under one cover, had been further revised and brought up to date ready for publication. The wrought data, however, had still to be reconciled with the American Iron and Steel Institute figures which at that time were not available. At the November meeting, committee members made a preliminary reconciliation between the A.I.S.I. and the A.S.T.M. figures and agreed to finish the work within the next two or three months, if at all possible.

Although Subcommittee I held no meeting during the A.S.T.M. Spring Group Meetings, it was able to report that everything but a few data on wire were ready for final editing and submission to A.S.T.M. Headquarters.

Subcommittee IV on Methods of Corrosion Testing: (F. L. LaQue, chairman).—The principal activity of this subcommittee has been the organization of a symposium to be held at the Annual Meeting in June, 1949 The topic is to be a critical appraisal of the tests commonly used for the evaluation of the corrosion resistance of stainless steels with particular regard to their relation to practical experience with these alloys in environments different from those of the tests, and the manner in which these relationships are influenced by steel composition, especially very low-carbon content.

A special subgroup made another inspection of stainless steel as used in architectural applications in New York, Philadelphia, and Atlantic City. The report of this inspection is appended hereto.

At the meeting of the subcommittee in March, it was decided to proceed with a comprehensive program of atmospheric corrosion tests that have been under discussion for some years. The immediate step will be to secure the thousands of test specimens and get them prepared for exposure when the test sites are ready

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[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

Subcommittee V on Mechanical Testing.—R. H. Heyer is now chairman, replacing T. F. Olt. A comprehensive program to secure information on certain moot questions in the testing of stainless steel was set up at a meeting held in March, 1948. In July, prepared sheet tension test specimens were sent out to the cooperating laboratories. The last returns from these eight laboratories were received during February, 1949, and compiled in the form of a report which showed that:

1. The method of controlling speed of testing by a schedule of time of test from yield to fracture gave much better agreement between the cooperating laboratories than other methods tried previously.

2. Offset yield strength determination is subject to errors caused by poor load-deformation curves and by difficulties in selecting the modulus line. The yield strength determined by 0.5 per cent extension under load is somewhat less sensitive to the shape of the elastic portion of the curve.

3. The sensitivity of several austenitic grades to speed of testing is a reflection of their sensitivity to temperature during plastic deformation, as evidenced by the results of the "damp cloth test" by R. A. Lincoln. All phases of the report were discussed at the meeting but no recommendations for specification changes were made, pending further study of the report.

The results obtained in these four round-robin tension tests conducted by Subcommittee V have been published in the ASTM BULLETIN.[3]

Subcommittee VI on Metallography: (Russell Franks, chairman).—The work of this subcommittee has progressed to the point where all of the samples of the 18 per cent chromium, 8 per cent nickel steels with and without molybdenum have been exposed to high temperatures. These samples were held at 1200 to 1500 F. for 24 hr. and for 500 hr. The samples so treated have been machined and Charpy impact test specimens have been distributed to the cooperating laboratories for impact tests. After the impact tests have been completed the next step will be to distribute samples for metallographic examination and X-ray diffraction tests to determine the existence of sigma phase. This work will be carried on simultaneously with etching experiments to determine whether an etchant can be found that will identify the sigma phase by metallographic means so that it will not be necessary to resort to X-ray diffraction examination.

Subcommittee VIII on Specifications for Wrought Products: (J. K. Findley, chairman) has been considering changes in the chemical composition requirements in Specifications A 276 covering hot-rolled and cold-finished corrosion resisting steel bars and also is recommending certain changes in physical test requirements so that these can be adopted as standard, as given earlier in this report.

Subcommittee IX on Specifications for Flat Products: (H. A. Grove, chairman recommended the changes in Specifications A 176 and A 240 concerning yield strength determination, given earlier in this report. These changes would make the 0.2 per cent offset method the preferable one with 0.5 per cent under load the alternate method. The subcommittee also recommended the changes covering the mechanical property requirements of type 410 in Specifications A 240. The addition of two new grades to Specifications A 240 was considered but it was decided not to include type 310, grade "R," until certain differences in chemical composition between that given and that desired by The American Society of Mechanical Engineers are resolved. Type 405 is to be added to this specification and designated as grade 0." The chemical composition is to be the same as for the alloy in Specifications A 263.

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[3] ASTM BULLETIN, No. 158, May, 1949, p. 57.

Consideration of the addition of other grades to Specifications A 240, including type 309, 0.08 per cent maximum carbon, type 309 plus columbium and type 316 plus columbium, is being further considered, and representatives of the subcommittee will meet with the A.S.M.E. Boiler Code Committee for discussion as to the necessity of adding them to Specifications A 240 at the present time.

Subcommittee X on Specifications for Castings: (J. J. Kanter, chairman) held a meeting on March 1, 1949, to review further the differences between the chemical composition of certain grades in the two general casting Specifications A 296 and A 297, and as a result the subcommittee recommends acceptance by Committee A-10 of the changes in composition detailed earlier in this report.

Subcommittee XI on Specifications for Tubular Products: (J. J. B. Rutherford, chairman) prepared with Committee A-1 on Steel the Tentative Specification A 312 – 48 T previously mentioned. The chairman of the subcommittee has also served in the capacity of chairman of the Subcommittee on Stainless Steel Pipe of the A.S.A. Sectional Committee B 36 on Wrought Iron and Steel Pipe. There will be available shortly an American Standard on Stainless Steel Pipe which it is expected will be the A.S.T.M. Standard.

This report has been submitted to letter ballot of the committee, which consists of 90 members; 52 members returning their ballots, of whom 50 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

Jerome Strauss,
Chairman.

H. D. Newell,
Secretary.

Editorial Note

Subsequent to the Annual Meeting, Committee A-10 presented to the Society through the Administrative Committee on Standards the following recommendations:

Revision of Tentative Specifications for:

Corrosion-Resistant Iron-Chromium and Iron-Chromium-Nickel Alloy Castings for General Application (A 296 – 49 T), and

Heat-Resistant Iron-Chromium and Iron-Chromium-Nickel Alloy Castings for General Application (A 297 – 49 T).

These recommendations were accepted by the Standards Committee on December 21, 1949, and the revised tentative specifications appear in the 1949 Book of A.S.T.M. Standards, Part 1.

APPENDIX

REPORT OF SPECIAL COMMITTEE ON INSPECTION OF STAINLESS STEEL ARCHITECTURAL STRUCTURES

In order to obtain information on the behavior of corrosion-resistant steels under conditions of actual service, a special committee was appointed in 1937 to inspect several architectural installations of stainless steel. The special committee has periodically inspected the installations at the Chrysler and Empire State Buildings in New York City, the Philadelphia Saving Fund Society Building in Philadelphia, and several building fronts along the boardwalk at Atlantic City, N. J.

Inspections of these installations were made in 1937, 1944, and 1947 and their condition reported in the 1939 and 1948 *Proceedings*[1] and in the "Symposium on Atmospheric Weathering of Corrosion-Resistant Steels."[2]

Observations made during the 1948 inspection are summarized as follows:

Chrysler Building, New York City, June 8, 1948:

The sheathing and trim on this building were installed in 1929–30, and consist of type 302 stainless steel. Locations examined were the observation platform on the sixty-first floor, where the gargoyles are located, the spire base on the level equivalent to the seventy-eighth floor, and store front and doorway installations on the street level.

Due to the inaccessibility of the external sheathing on the spire, a thorough examination of this section was impossible. However, the areas around the sliding door openings showed little or no attack, although the sheathing had a dirty gray appearance, most of which is probably dirt and soot accumulation. Rubbing with a mild abrasive disclosed bright metal, with very shallow pits.

On the sixty-first floor, discoloration similar to that in the spire was apparent. Areas near soldered joints in the gargoyle construction did not appear to be as discolored as areas some distance away from the joints. This was presumed to be due to cleaning of the original oil on the surface by an alkaline wiping after soldering. The areas near soldered joints received such wiping, while the remainder of the surface did not, and it is presumed that dirt accumulated to a greater extent on the oiled surface.

The stainless steel installations on the street level receive a cleaning twice a year, a water solution of "Spic and Span" being employed currently. Flat surfaces remain fairly bright, but in crevices some slight amount of rust staining was evident. Such staining is not considered to be of a serious nature, and close examination revealed only very shallow attack at such spots.

Window trim on the Lexington Ave. side and door sills at the entrance to Schrafft's Restaurant on Forty-second St. have buckled due to the absence of expansion joints in the construction.

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 39, pp. 197–202 (1939); Vol. 48, p. 137 (1948).

[2] "Symposium on Atmospheric Weathering of Corrosion-Resistant Steels," Am. Soc. Testing Mats., April, 1947.

This is quite noticeable on the windows on the Lexington Avenue side of the building, and some of the spot welds, located at regular intervals along the trim, have broken loose, the trim having a wavy appearance when examined at an acute angle. This occurrence illustrates the advisability of employing expansion joints in such applications where buckling due to expansion may be likely to occur.

Empire State Building, New York City, June 8, 1948:

This building, like the Chrysler Building, used type 302 stainless steel for its exterior sheathing and trim. On the sides of the building the vertical spandrels are stainless steel, while the horizontal sections separating the windows are cast aluminum. The stainless steel was installed in 1931 and has not been cleaned since. Inspection included the spandrels at the sixth-floor level, the observation platform on the eighty-sixth floor, sheathing on the tower at the one hundred and second-floor level, and the new spandrels on the seventy-eighth floor, the site of the bomber crash in 1945.

In general, the same sort of discoloration as on the Chrysler Building was observed on the Empire State Building installations. The spandrels on the sixth floor level seemed to be somewhat darker in appearance than the installations at the top of the building. Minute pitting of no serious nature could be seen by the use of a magnifying glass, and the discoloration could be removed by a mild abrasive to disclose a bright shiny surface.

New stainless steel installations on the seventy-eighth floor were brighter in appearance than the original spandrels both above and below.

Sheathing on the tower at the one hundred and second-floor level did not appear to be as discolored as the sheathing on the spire of the Chrysler Building. This may be due to less contamination of the atmosphere at the higher altitude.

The building management representative who accompanied the inspection group expressed the opinion that the stainless steel installations on this building have been entirely satisfactory to date, and no future difficulties are anticipated.

Philadelphia Saving Fund Society Building, Philadelphia, Pa., June 9, 1948:

This building was opened in 1932. A considerable amount of type 302 stainless steel was employed both inside and outside as marquees, panels in entry ways, elevator panels, wall panels, escalator trim, facing of bank vaults, and kitchen equipment in the bank kitchen.

The installations on the interior of the bank were observed to be in excellent condition, as reported previously.

On the exterior installations the surfaces which have received normal periodic cleaning, such as window trim and entry door panels, were found to be in excellent condition. However, ceiling trim in some of the store entrance ways had obviously not received periodic cleaning. Some rust staining was apparent and the horizontal surfaces were either rusty or dirty gray in appearance. Probably all of this could be readily removed by a good cleaning, and its recurrence prevented by including these surfaces in the normal exterior cleaning program.

Boardwalk Store Fronts, Atlantic City, N. J., June 9, 1948:

Perhaps the most interesting observation made at Atlantic City was the great increase in the use of stainless steel for store fronts and exterior trim in the past few years. At certain sections of the boardwalk, every building partially or completely uses stainless steel trim on its exterior. A few of the store managers stated that they were pleased with the metal's performance but that they have to clean the metal periodically in order to overcome superficial rust staining. Most store owners have formed the practice of cleaning their store fronts about once a week with soap and water. In a few instances where a highly lustrous appearance is desired, such as at moving picture theaters, the metal is wiped off once a day. The Strand Theater is one such installation which has received this attention, and the stainless steel shows no signs of pitting or other forms of deterioration after seven years.

Some buildings, such as the Howard Johnson restaurant, are not in use during the winter and hence receive no maintenance during that period. The inspection group was informed that at this restaurant a covering of grease is applied on the stainless steel exterior, which protects it very well throughout the winter.

At the duPont Exhibit Building, stainless steel exterior trim and panel was installed in 1936. A clear lacquer coating is applied about once a year to the stainless surface to eliminate the necessity of periodic cleaning. At the time of this inspection the present coating had been on for a considerable time. It was apparent that the coating used had not given complete protection to the metal, and considerable rust staining was evident. The ceiling of the entrance to the exhibit was badly rust stained over a large portion of the surface, but close examination revealed only shallow pitting of the surface. However, the appearance of such stained surfaces was not attractive.

Other buildings inspected included the former Regis Restaurant, which is now the Tides Tavern, Gettleman's Store, which is now a drug store, and the Apollo Theater. This latter building has a stainless steel marquee, the ceiling of which contains grooves indented in the surface so as to form a design. Although this marquee receives periodic cleaning, the grooves are somewhat inaccessible and contain rust stains not removed by cleaning.

Conclusions:

The inspections of 18 per cent chromium, 8 per cent nickel stainless steel architectural installations, some of which are 18 years old, indicate that for the most part this material will give a good account of itself if properly designed, installed, and maintained. Even when no periodic cleaning is practiced, such stainless steel may be expected to yield a long useful life, although it may become dirty and develop incipient shallow pitting. Such pitting as has been observed is apt to be more prevalent in crevices where dirt may collect. However, there are no indications that the useful life of such installations is impaired by such pitting.

In seashore locations rust staining may be anticipated unless frequent periodic cleaning programs are carried out. But where such cleaning programs are practiced, the stainless steel may be maintained with its original bright lustrous appearance indefinitely.

Those participating in the 1948 inspection were:

H. A. Grove
G. D. Barrett
D. Gathers
R. E. Paret
G. Pleam
H. L. Priestley
E. A. Tice

Respectfully submitted on behalf of the special committee,

H. A. GROVE,
Chairman.

REPORT OF COMMITTEE B-1

ON

WIRES FOR ELECTRICAL CONDUCTORS*

Committee B-1 on Wires for Electrical Conductors held two meetings during the year: one in New York, N. Y., on April 14, 1949, and one in Atlantic City, N. J., on June 30, 1949. Meetings of the Advisory Committee and of Subcommittees IV, V, VI, and VII were also held during the year.

The committee reports, with deep regret, that during the year it lost the services of three of its long-time active workers, two by retirement, and one by death. The two who retired were Alfred Bellis and C. S. Gordon, chairmen respectively of Subcommittees III and II; the former with nearly 20 years' service, and the latter with 15. The death on February 2, 1949, of J. R. Becker deprived the committee of another member whose active participation in its work for more than 20 years will long be remembered.

The committee now consists of 73 members, of whom 37 are classified as producers, 26 as consumers, and 10 as general interest members.

The Regulations Governing Committee B-1 were amended during the year to permit election, by unanimous action of the Advisory Committee, of not more than five honorary members. An honorary member shall have performed especially meritorious service as a member of the committee.

Upon acceptance of this amendment to the Regulations, Messrs. Bellis and Gordon were elected honorary members of Committee B-1.

At the April meeting, it was voted to discharge Subcommittee III after the June meeting and to distribute its work on rods to the respective conductor Subcommittees IV, V, VI, and VII.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1948 Annual Meeting, Committee B-1 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Revision of Standard Specifications for:

Bronze Trolley Wire (B 9 – 46),
Copper Trolley Wire (B 47 – 46), and
Figure 9 Deep-Section Grooved and Figure 8 Trolley Wire for Industrial Haulage (B 116 – 46).

These recommendations were accepted by the Standards Committee on September 29, 1948, and the tentative revisions appear in the 1948 Supplement to Book of A.S.T.M. Standards, Part I-B.

REVISIONS OF TENTATIVES

The committee recommends that the following four specifications be revised as indicated and continued as tentative:

Tentative Specifications for Rope-Lay-Stranded Copper Conductors Having Bunch-Stranded Members, for Electrical Conductors (B 172 – 45 T),[1] revised as follows:

Section 3(c).—Delete all of this paragraph except the first sentence.

Section 7 (a).—Change to read as follows:

(*a*) Tests for the physical and electrical properties of wires composing conductors made from annealed copper wire or from coated soft copper wire may be made before stranding, but not on wires removed from the conductor.

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*Presented at the Fifty-second Annual Meeting of the Society, June 27-July 1, 1949.

[1] 1946 Book of A.S.T.M. Standards, Part I-B.

Section 5 (c).—Delete this paragraph, relettering Paragraph 5(*d*) accordingly.

Explanatory Notes.—Delete Note 5, renumbering the subsequent notes accordingly.

Tentative Specifications for Rope-Lay-Stranded Copper Conductors Having Concentric-Stranded Members, for Electrical Conductors (B 173 – 47 T),[2] revised as follows:

Sections 3 (c) and 7 (a).—Make the same changes indicated above for Sections 3(*c*) and 7(*a*) of Specifications B 172.

Explanatory Notes.—Delete Note 4, renumbering the subsequent notes accordingly.

Tentative Specifications for Bunch-Stranded Copper Conductors for Electrical Conductors (B 174 – 45 T),[1] revised as follows:

Sections 3 (c) and 7 (a).—Make the same changes indicated above for Sections 3(*c*) and 7(*a*) of Specifications B 172.

Explanatory Notes.—Delete Note 3, renumbering the subsequent note accordingly.

Tentative Specifications for Hard-Drawn Aluminum Wire for Electrical Purposes (B 230 – 48 T),[3] revised as follows:

Section 6 (b).—Change to read as follows:

(*b*) Ten per cent, but not less than five coils or spools (or all if the lot is less than five) from any lot of wire shall be gaged at three places. If accessible, one gaging shall be taken near each end and one near the middle. If any of the selected coils or spools fails to conform to the requirements prescribed in Paragraph (*c*), all coils or spools shall be gaged in the manner specified.

Sections 6 (c), 8 (b)(1), and Table I.—Change the minimum wire size from "0.0180 in." to "0.0105 in."

REVISIONS OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions in the following six standards. The adoption as standard is also recommended of the tentative revisions[3] in Specifications B 9, B 47, and B 116, as issued in September, 1948. The committee accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society.

Standard Specifications for Hard-Drawn Copper Wire (B 1 – 47) and for Medium-Hard-Drawn Copper Wire (B 2 – 47), revised by deleting the last sentence of Section 5 (*b*) in both standards.

Standard Specifications for Hard-Drawn Copper Alloy Wires for Electrical Conductors (B 105 – 47), revised by deleting the last sentence of Section 7 (*b*).

Standard Specifications for Bronze Trolley Wire (B 9 – 46), revised as follows:

Table IV.—Combine this table on area requirements with the area and weight figures given in the new Fig. 1 showing the standard sections in the "tentative revision" referred to above. Renumber the subsequent tables accordingly.

Section 9.—Change the references in this section from "Table IV" to "Fig. 1."

Standard Specifications for Copper Trolley Wire (B 47 – 46), revised as follows:

Table III.—Make the same change indicated above for Table IV of Specifications B 9.

Section 9.—Change the references in this section from "Table IV" to "Fig. 1."

Standard Specifications for Figure-9 Deep-Section Grooved and Figure-8 Copper Trolley Wire for Industrial Haulage (B 116 – 46), revised as follows:

Tables III and IV.—Combine these tables on area requirements with the area and weight figures given in the new Figs. 2 and 3 showing the standard sections in the "tentative revision" referred to above.

Section 5.—Change the references to Tables III and IV to Figs. 1 and 2, respectively.

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following one method and three specifications be approved for reference to letter ballot of the Society for adoption as standard without revision. These specifications have stood for one year published as tentative, during which time no criticisms or suggestions for improvement of a material nature have been received.

Tentative Method of Test for:

Resistivity of Electrical Conductor Materials (B 193 – 48 T).

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[2] 1947 Supplement to Book of A.S.T.M. Standards, Part I-B.

[3] 1948 Supplement to Book of A.S.T.M. Standards, Part I-B.

Tentative Specifications for:

Cored, Annular, Concentric-Lay-Stranded Copper Conductors (B 226 – 48 T),

Concentric-Lay-Stranded Copper Covered Steel Conductors (B 228 – 48 T), and

Rolled Aluminum Rods (EC Grade) for Electrical Purposes (B 233 – 48 T).

The committee recommends that the following five specifications be approved for reference to letter ballot of the Society for adoption as standard with revisions as indicated:

Tentative Specifications for Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft (B 8 – 48 T), with the following revision:

Section 12.—In the first sentence, after the words "or lengths," add "and number of lengths."

Tentative Specifications for Soft Rectangular and Square Bare Copper Wire for Electrical Conductors (B 48 – 48 T), revise by the addition of the following notes to the Explanatory Notes:

NOTE 11.—"Square mils" is a term used to express cross-sectional area of square and rectangular sections. A square mil is the area of a square one mil on each side. Thus, if dimensions of a rectangular section are expressed in mils, the area of that section in square mils is the product of thickness times width. The relationship between circular mils and square mils is that of a circle to its circumscribing square. Thus, one circular mil = 0.7854 square mils.

NOTE 12.—Square wire sizes sometimes are expressed in terms of A.w.g. sizes, as "No. 8 A.w.g. Square." This terminology is confusing and its use is not recommended. However, when a square wire size is expressed in this manner, it refers to a square circumscribing a circle whose diameter is that of a round wire of the specified A.w.g. size.

Tentative Specifications for Hard-Drawn Copper-Covered Steel Wire (B 227 – 48 T), with the following revision:

Section 12.—Change the heading to read "Packing and Marking," and add the following as a new Paragraph (*c*):

(*c*) Each coil shall bear a tag showing the manufacturers' name or trademark, size, and class of material. If additional information is to be required on the tags, it shall be arranged with the manufacturer at the time of purchase.

Tentative Specifications for Concentric-Lay-Stranded Copper and Copper-Covered Steel Composite Conductors (B 229 – 48 T), with a revision in Section 4 (*a*), changing the maximum length of lay from "18" to "20" times outside diameter.

Tentative Specifications for Concentric-Lay-Stranded Aluminum Conductors, Hard-Drawn (B 231 – 48 T), revise by changing the heading of the second column in Table II from "Copper Conductivity Equivalent" to "Hard-Drawn Copper Equivalent."

TENTATIVE CONTINUED WITHOUT REVISION

The committee recommends that the Tentative Specifications for Concentric-Lay-Stranded Aluminum Conductors, Steel-Reinforced (ACSR) (B 232 – 48 T) be continued as tentative.[4]

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[5]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Editorial and Records (A. A. Jones, chairman) continued its editorial review of specifications and is compiling a history of the committee's activities.

Subcommittee II on Methods of Test and Sampling Procedure (J. B. Dixon, chairman) is recommending the adoption as standard of Method B 193 (for resistivity) and has a task group engaged in writing a suitable sampling procedure for B-1 Specifications and has prepared a preliminary draft based on statistical methods as developed by Committee E-11 on Quality Control of Materials. Extended trials now are in progress in the plants of a number of the producer members. When completed, this investigation probably can be the basis of a technical paper sponsored by Committee B-1 for presentation to the Society.

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[4] Revision of these specifications has since been approved by the Administrative Committee on Standards, see Editorial Note, p. 145.

[5] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

Subcommittee IV on Conductors of Copper and Copper Alloys (H. H. Stout, Jr., chairman) prepared the tentative revisions of the three trolley wire specifications (B 9, B 47, and B 116) previously mentioned and is now recommending their adoption as standard. The subcommittee is also recommending the adoption as standard of Specifications B 8, B 48, both with minor changes, and B 226, without change.

The subcommittee has a task group which has started the preparation of a specification for the conductors of segmental-type, single-conductor cable in sizes up to, and including, 4,000,000 cm. The task group which prepared the recent revision of the trolley wire specifications is now quite active in the design of a suitable standard gage, ultimately to replace the slip fitting presently authorized for inspection. Another task group, working on adequacy of methods of determination of weights, areas, and resistivities in all B-1 Specifications, has completed its work, but has not yet reported its recommendations to the committee.

Also in Subcommittee IV a task group on revision of significant figures in all tables of wire sizes has deferred work on this project, awaiting information from the National Bureau of Standards on the bases of calculation which will be used in the forthcoming revision of Circular No. 31. The bases to be used for electrical resistance values cannot be established until agreement is reached in the International Electrotechnical Commission on how to treat the value of the ohm. In this connection, a special task group of Committee B-1 was appointed during the year to consult with the Bureau of Standards on the revision of Circular No. 31. As a result of meetings and considerable correspondence, a report was prepared, incorporating a number of recommendations for consideration by the Bureau in revising Circular No. 31.

Subcommittee V on Conductors of Ferrous Metals (L. H. Winkler, chairman) expects to complete a tentative specification for the steel wire used for reinforcement of aluminum cable before the end of the year.

Subcommittee VI on Composite Conductors of Copper and Steel (C. E. Ambelang, chairman) is recommending the adoption as standard of Tentatives B 227 and B 229, with minor changes, and B 228 without change, as mentioned earlier in this report. The subcommittee has deferred writing a specification for copper and steel composite conductors as there is no current demand for such specification.

Subcommittee VII on Conductors of Light Metals (P. V. Faragher, chairman) is collecting data on wire characteristics employing proposed sampling procedures based on statistical methods so that the sampling procedures requirements in B 230 (for hard-drawn aluminum wire) can be improved. This specification, with minor changes, and specification B 232 (for A.C.S.R.) are being continued as tentative but the subcommittee is recommending the adoption as standard of specifications B 231 (for aluminum stranded cable) and B 233 (for rolled aluminum rods—EC grade).

This report has been submitted to letter ballot of the committee, which consists of 72 members; 55 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

J. H. FOOTE,
Chairman.

A. A. JONES,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee B-1 presented to the Society through the Administrative Committee on Standards the recommendation that the Specifications for Standard Weight Zinc Coated (Galvanized) Steel Core Wire for Aluminum Conductors, Steel Reinforced (ACSR) be accepted for publication as tentative.

This recommendation was accepted by the Standards Committee on December 22, 1949, and the new tentative appears in the 1949 Book of A.S.T.M. Standards, Part 2, bearing the designation B 245–49T.

REPORT OF COMMITTEE B-2
ON
NON-FERROUS METALS AND ALLOYS*

Committee B-2 on Non-Ferrous Metals and Alloys held one meeting, on June 24, 1948, in Detroit, Mich., during the Annual Meeting of the Society. With this meeting of Committee B-2, E. E. Thum retired as chairman of the committee after twenty years of service as an officer, eleven as secretary and nine as chairman. Committee B-2, at the meeting, expressed to Mr. Thum its appreciation for his many years of service, and the Advisory Committee, at its meeting in August, by unanimous action appointed Mr. Thum an Honorary Vice-Chairman of Committee B-2.

Since this June meeting, the work of Committee B-2 has continued to be handled by correspondence.

The Advisory Committee met in New York, N. Y., on August 17, 1948, approved changes in the membership of Committee B-2 and of the subcommittees, and accepted reports of the work of the subcommittees. The Advisory Committee appointed a Special Task Group, in March 1948, to revise the By-laws. The new By-laws, as further revised by the Advisory Committee were accepted by letter ballot of Committee B-2 on November 23, 1948.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1948 Annual Meeting, Committee B-2 presented to the Society through the Administrative Committee on Standards the following recommendations:

Revision of Tentative Specifications for:
Soft Solder Metal (B 32 – 46 T), and
White Metal Bearing Alloys (B 23 – 46 T).

These recommendations were accepted by the Standards Committee on September 29, 1948, and the revised tentatives appear in the 1948 Supplement to Book of A.S.T.M. Standards, Part I-B.

The proposed Specifications for Metallic Antimony were accepted as tentative by the Standards Committee on February 3, 1949. The new tentative specifications have been assigned the designation B 237 – 49 T.

REVISIONS OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions in the following two standards and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these revisions may be referred to letter ballot of the Society:

Standard Specifications for Slab Zinc (Spelter) **(B 6 – 48):**[1]

Table I.—Add the following as a new Note 3 to this table:

> NOTE 3.—Where it is specified by the buyer at the time of purchase that the special high-grade zinc is to be used for the manufacture of zinc-base die-casting alloy ingot, the maximum permissible tin content shall be 0.002 per cent and the maximum permissible lead content shall be 0.005 per cent.

Standard Specifications for Pig Lead **(B 29 – 43):**[2]

Section 6.—Change to read as follows:

> 6. (*a*) One pig shall be taken to represent each ton of lead in the lot. The pigs thus selected shall be sampled by one of the methods de-

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] 1948 Supplement to Book of A.S.T.M. Standards Part I-B.

[2] 1946 Book of A.S.T.M. Standards, Part I-B.

scribed in the following paragraphs (*b*), (*c*), (*d*) and (*e*). Whenever the surface of the pigs to be sampled is dirty, it should be cleaned so that none of the dirt or foreign material gets into the sample.

(*b*) *Sawing.*—The pigs may be sawed completely through as illustrated in Fig. 1. The sawings from all the pigs shall be mixed thoroughly and quartered and the samples for analysis taken from the mixed material. The sawings must be free from all extraneous material, particularly iron introduced from the saw blade. All sawings must be treated with a strong magnet in order to remove iron.

(*c*) *Drillings.*—The pigs may be drilled at least halfway through from two opposite sides as illustrated in Fig. 2. A drill of about ½ in. in diameter is preferred. In drilling, the holes shall be spaced along a diagonal line from one corner of the pig to the other. Sampling in this manner may be so arranged that one or more holes are made in each of several pigs of a group so placed that they represent consecutive positions on the diagonal of a single pig. (See illustration in Fig. 2). The drillings may be clipped and mixed, and the samples for analysis drawn from the mixed material; or they may be melted in a clean crucible and either granulated by pouring into distilled water and drying thoroughly, or cast into thin slabs which shall be sawed through completely in several places and the sawings treated as described in Paragraph (*b*).

(*d*) *Kettle.*—The pigs, or portions of the lot selected shall be melted in a clean kettle. The melt must be made at as low a temperature as possible in order to prevent excessive drossing. (It is recommended that the temperature of the melt not exceed 685 F. and that the molten bath be stirred immediately prior to the sampling.) While stirring the bath, a sample in a preheated ladle may be taken and cast into thin sample bars approximately 8 in. in length, 1¼ in. in width and not to exceed ⅜ in. in thickness. (See Note.) From the bar so cast, make saw cuts from each side, halfway across the slab. Saw cuts are to be staggered, so that they are approximately ½ in. apart. The cuts shall be made so that no cut is closer than 1 in. to either end of the slab.

NOTE.—Molds for slabs may be made by placing two sections of steel channel, each section not to exceed ⅜ in. in thickness, on a steel plate and arranging the open side of each section of the channel so that the ends of the channels butt against a steel strip fastened to the steel plate. Such an arrangement will provide a mold into which the duplicate samples may be cast and from which samples may be removed easily.

(*e*) *Spectrographic and Related Specimens.*—From slabs cast in accordance with Paragraph (*d*), cut two sections of approximately ¼ in. in width across the bar. These sections should be cut at locations one-third the distance from each end of the slab.

If preferred, specimens may be obtained as follows: Prepare a hard glass tube fitted with a large rubber bulb. Expel the air from the bulb and dip the open end of the tube into the molten bath of lead. Allow enough of the molten metal to enter the tube to form a metallic pin at least 5 in. in length. After the tube has cooled, break the glass and clean the metallic pin prior to use for spectrographic or other examination. The procedure may be used either in molten metal resulting from the melting of sawings or drillings or from the bath of molten metal while in use.

(*f*) The minimum weight of sample required for chemical analysis is 600 g. (1800 g. for necessary three samples). The sawings or drillings shall be mixed thoroughly and shall be divided into three equal parts, each of which shall be placed in a container and sealed; one for the manufacturer, one for the purchaser, and one for an umpire, if necessary.

(*g*) In case of dissatisfaction, either party may require that the material be resampled in the presence of representatives of the manufacturer and the purchaser.

Figure 2.—Delete all references to "punching" in the note and title of this figure.

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following tentatives be approved for reference to letter ballot of the Society for adoption as standard, without revision.

Tentative Specifications for:

White Metal Bearing Alloys (Known Commercially as "Babbitt Metal") (B 23 - 48 T),[1]

Soft Solder Metal (B 32 - 48 T),[1] and

Fire-Refined Copper for Wrought Products and Alloys (B 216 - 47 T).[3]

REAFFIRMATION OF STANDARDS

The committee recommends reaffirmation of the following standards which have been published for six years or longer without revision and which are to be continued as such:

Standard Specifications for:[2]

Lake Copper Wire Bars, Cakes, Slabs, Billets, Ingots, and Ingot Bars (B 4 - 42),

Electrolytic Copper Wire Bars, Cakes, Slabs, Billets, Ingots, and Ingot Bars (B 5 - 43),

Nickel (B 39 - 22),

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[1] 1947 Supplement to Book of A.S.T.M. Standards, Part I-B.

Rolled Zinc (B 69 – 39),
Lead-Coated Copper Sheets (B 101 – 40), and
Electrolytic Cathode Copper (B 115 – 43).

TENTATIVE CONTINUED WITHOUT REVISION

The committee recommends that the Tentative Specifications for Fire-Refined Casting Copper (B 72 – 47 T)[3] be continued as tentative without revision pending clarification of the market condition for the material covered by these specifications.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Refined Copper (William E. Milligan, chairman) reviewed the specifications under its jurisdiction and made editorial changes, correlating them with the Tentative Classification of Copper (B 224 – 48 T) in Specifications B 4, B 5, B 72, B 115, B 170, and B 216. The subcommittee recommended the adoption as standard of Tentative Specifications B 216.

Subcommittee II on Refined Lead, Tin, Antimony and Bismuth (Sidney Rolle, chairman) prepared the Tentative Specifications for Metallic Antimony (B 237 – 49 T) mentioned above. As previously reported, the revised sampling method in Standard Specifications B 29 has been under review by Committee E-3 on Chemical Analysis of Metals. Committee E-3 has approved this revision which is, therefore, recommended for immediate adoption.

Subcommittee III on White Metals and Alloys (G. H. Clamer, chairman) reviewed Tentative Specifications B 23 and B 32, and recommended the adoption of both tentatives as standard without revision.

Subcommittee IV on Refined Zinc and Wrought Zinc (E. H. Bunce, chairman) prepared the revision of Standard Specification B 6 which provides an additional control for special high-grade zinc when this grade is to be used in the manufacture of zinc-base die-casting alloy ingot.

Subcommittee VI on Coated Metals (F. L. Scovill, Jr., acting chairman).—Mr. Scovill was appointed acting chairman succeeding Griffith Williams, Jr. who resigned from the committee on transfer of his work to the Pacific Coast operations of his company. The subcommittee continued the review of Standard Specifications for Lead-Coated Copper Sheet (B 101 – 40), which review aims to determine if revision of the specifications is necessary or desirable.

Subcommittee VII on Refined-Nickel and High-Nickel Alloys, Cast and Wrought (O. B. J. Fraser, chairman) is revising the Tentative Specifications for Nickel-Copper Alloy Plate, Sheet, and Strip (B 127 – 41 T) and the Tentative Specifications for Nickel-Copper Alloy Rods and Bars (B 164 – 41 T).[5] The reapproval of Standard Specifications B 39, as previously indicated in this report, was recommended. The subcommittee is also reviewing and revising the remaining specifications under its jurisdiction and expects to recommend all the proposed revisions of these specifications in such time that the revisions will appear in the 1949 Book of A.S.T.M. Standards.[5]

This report has been submitted to letter ballot of the committee, which consists of 132 members; 82 members returned their ballots, of whom 79 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

BRUCE W. GONSER,
Chairman.

G. HOWARD LEFEVRE,
Secretary.

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[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

[5] See Editorial Note, p. 149.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee B-2 presented to the Society through the Administrative Committee on Standards the following recommendations:

Revision of Tentative Specifications for:

Nickel-Copper Alloy Plate, Sheet, and Strip (B 127 - 41 T),
Nickel Rods and Bars (B 160 - 41 T),
Nickel Cold-Drawn Pipe and Tubing (B 161 - 41 T),
Nickel Plate, Sheet, and Strip (B 162 - 41 T),
Nickel, Nickel-Copper Alloy, and Nickel-Chromium-Iron Alloy Seamless Condenser Tubes and Ferrule Stock (B 163 - 41 T),
Nickel-Copper Alloy Rods and Bars (B 164 - 41 T),
Nickel-Copper Alloy Cold-Drawn Pipe and Tubing (B 165 - 41 T),
Nickel-Chromium-Iron Alloy Rods and Bars (B 166 - 41 T),
Nickel-Chromium-Iron Alloy Cold-Drawn Pipe and Tubing (B 167 - 41 T), and
Nickel-Chromium-Iron Alloy Plate, Sheet, and Strip (B 168 - 41 T).

These recommendations were accepted by the Standards Committee on December 14, 1949, and the revised tentative specifications appear in the 1949 Book of A.S.T.M. Standards, Part 2.

REPORT OF COMMITTEE B-3
ON
CORROSION OF NON-FERROUS METALS AND ALLOYS*

Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys held two meetings during the past year: one in Detroit, Mich., on June 24, 1948, and the other in Chicago, Ill., on March 2, 1949.

The committee consists of 107 members of whom 87 are voting members; 31 are classified as consumers, 38 as producers, and 18 as general interest members.

REVISION OF TENTATIVE METHOD

The committee recommends that the Tentative Method of Salt Spray (Fog) Testing (B 117 - 44 T) be revised, as appended hereto.[1]

TENTATIVES CONTINUED WITHOUT REVISION

The committee also recommends that the following two methods be continued as tentative without revision:

Tentative Methods of Test for:

Total Immersion Corrosion Test of Non-Ferrous Metals (B 185 - 43 T), and

Alternate Immersion Corrosion Test of Non-Ferrous Metals (B 192 - 44 T).

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee III on Spray Testing (N. L. Foltz, chairman) prepared the revisions of Tentative Method B 117 mentioned above. The subcommittee will continue to study possible revisions in the salt spray method. A working group is to be appointed to survey present information and plan a test program.

A working group has been appointed to assemble information on the acetic acid-salt spray test as used for evaluating the quality of plated coatings on zinc-base die-castings.

Subcommittee VII on Weather (F. L. LaQue, chairman).—The principal activity of this subcommittee was through a subgroup consisting of C. P. Larrabee and O. B. Ellis who exposed specimens of iron and zinc at a number of test locations with the object of comparing the corrosivities of the atmospheres at the different test sites with respect to these two metals. In this program specimens have been exposed at Sandy Hook, N. J., State College, Pa., Brunot's Island, Pittsburgh, Pa., Kure Beach, N. C., Vandergrift, Pa., Kearny, N. J., Middletown, Ohio; and on the roof of the Port of New York Authority Building, New York, N. Y.

The number of specimens exposed at each site was sufficient for removals in groups after 1, 2, 4 and 8-yr. periods so that the test will be completed in 1956, with data being accumulated each year until then.

As a continuation of the work of the subgroup on instruments, its chairman O. B. Ellis has prepared a paper on

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* Presented at the Fifty-second Annual Meeting of the Society, June 27-July 1, 1949.

[1] This revised method was accepted by the Society and appears in the 1949 Book of A.S.T.M. Standards, Part 2.

[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

Effect of Weather on the Initial Corrosion Rate of Sheet Zinc which appears as an appendix to this report.

A third group under the chairmanship of L. G. von Lossberg has been organized to prepare a summary of available information on methods of measuring atmospheric pollution.

Subcommittee VIII on Galvanic and Electrolytic Corrosion (L. J. Gorman, chairman).—It is expected that by the end of May, 1949, the subcommittee will have on exposure the specimens of Parts 1 and 2 of its program on galvanic tests of magnesium alloys coupled to other metals. Part 1 consists of the coupling together of disk specimens and Part 2 consists of assemblies made by winding wires around a threaded rod to obtain galvanic coupling.

This report has been submitted to letter ballot of the committee, which consists of 87 voting members; 56 members returned their ballots, of whom 53 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

K. G. COMPTON,
Chairman.

A. W. TRACY,
Secretary.

APPENDIX

EFFECT OF WEATHER ON THE INITIAL CORROSION RATE OF SHEET ZINC

By O. B. Ellis[1]

Synopsis

The weight losses of 26 samples of sheet zinc exposed for periods of 28 days in a mild industrial atmosphere have been studied with relation to weather variations during the periods of exposure. There were five specimens in each sample. A multiple correlation analysis of the data has shown that the 28-day weight losses can be correlated with the number of hours of rainfall and the number of hours the relative humidity was at or near 100 per cent during the first five days of exposure. Rainfall and humidity after the first five days were much less effective in determining the corrosion rate than that during the early part of the exposure. The effect of the initial attack carries through to at least one year. Samples that had high initial corrosion rates showed higher corrosion rates after twelve months' exposure than the samples that corroded initially at low rates.

The weather conditions that resulted in great variations in the initial rate of attack on sheet zinc did not have a similar effect on the initial rate of corrosion of low-copper iron.

There are indications that the rate of corrosion of metals is influenced by conditions of weather. It is a well-established fact that unprotected metals corrode more rapidly in a marine or industrial location than in a rural community. Weight loss determinations have shown that for a given location there may be wide fluctuations in corrosion rates from year to year.

Larrabee (**1**)[2] has postulated that differences in corrosion rates are due to the length of time the surface is moist and the amount and nature of atmospheric contaminants. Copson (**2**) stated that the rate of corrosion depended on the quality and quantity of water reaching the metal surface. Dearden (**3**) has investigated the corrosion of iron at Derby and has apportioned varying percentages of total corrosion to several atmospheric and weather conditions. Evans (**4**) referred to Vernon's work on indoor corrosion of zinc, which showed the initial rates to be higher than the constant rate finally established.

There is no reason to doubt that water is necessary for the corrosion of metals, and that impurities in the water, whether it be rain or dew, have an influence on the final rate of corrosion.

The problem to be discussed in this paper is that of attempting to sort out some of the measurable variables of weather and trying to fit them into observed variations of weight loss for definite short periods of exposure in a single location. The effect of great variation in atmospheric contamination, such as the difference between rural and marine or industrial locations, is not a part of this discussion.

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[1] Senior Research Engineer, Research Laboratories, Armco Steel Corp., Middletown, Ohio.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 167.

In the spring of 1946, recording weather instruments were installed in the corrosion yard at Middletown, Ohio, so that representative weather data at the exposure location would be available. During the test, the weather instruments gave continuous records of temperature, relative humidity, rainfall, wind direction, and wind velocity. At a later date a pyrheliometer and a recording potentiometer were installed to measure specimen temperatures. In the early stages of the test, a special instrument was used to give an approximation of the length of time a specimen surface was wet.

WEATHER INSTRUMENTS

A general view of the corrosion yard showing the location of the weather instruments with respect to the exposed specimens is given in Fig. 1. Recommendations of the United States Weather Bureau were followed in determining the unobstructed space between various instruments. Certain minimum distances are necessary to prevent one instrument from interfering with another.

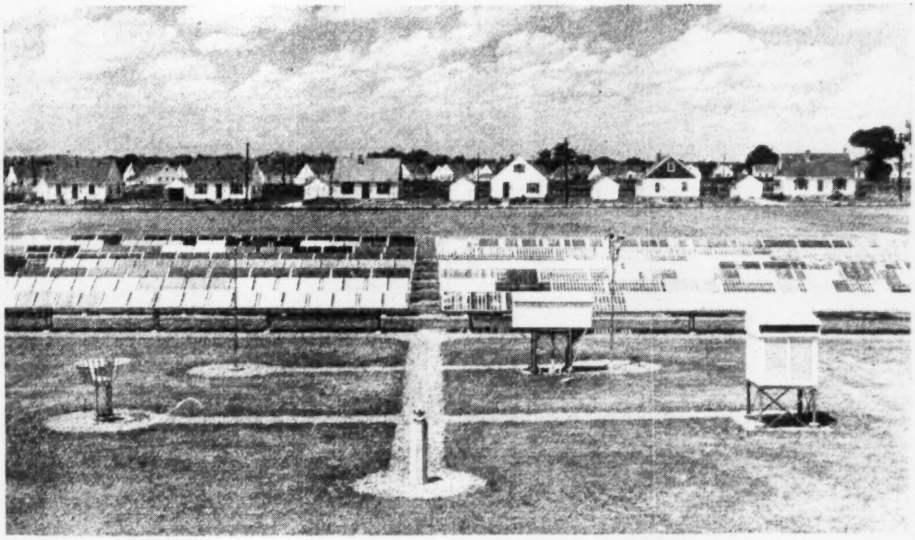

FIG. 1.—Recording Weather Instruments and Shelters.

The pyrheliometer is illustrated in Fig. 2. This instrument is, essentially, a differential thermocouple enclosed in a glass sphere. The active element consists of a disk and an annular ring, one blackened, the other white. The instrument is calibrated against the Smithsonian Institute silver-disk pyrheliometer and records total solar radiation in gram calories per square centimeter per minute. In normal use the pyrheliometer is mounted in such a way that the plane of the absorbing and reflecting surfaces is horizontal. The specimens exposed in the corrosion yard are inclined at an angle of 30 deg. facing south. Therefore, the pyrheliometer was mounted in a similar manner at a height above ground equal to that of the center specimen on the corrosion frames. Readings obtained from this instrument are directly related to the solar radiation incident upon the corroding specimens. The value of total radiation data in its application to corrosion of metals has not been studied at this time.

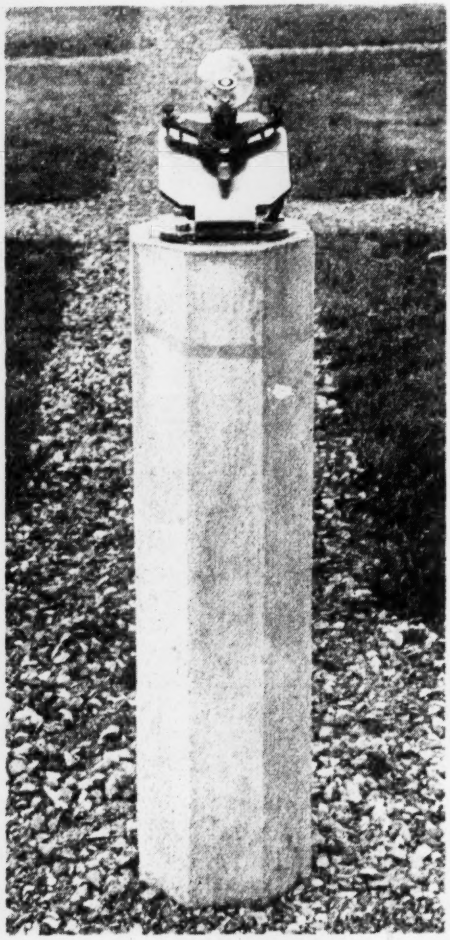

FIG. 2.—Pyrheliometer.

The recording rain gage is shown in Fig. 3. This is a conventional type instrument. The rainfall is received through an 8-in. diameter opening and drains through a funnel into a receiver. The receiver is mounted on a recording balance calibrated to read inches of rainfall. The recording cylinder is driven by a clock movement to record both the time of rain and the amount of precipitation. The rain gage has a total capacity of 12 in. of rainfall, which is ample for a seven-day period. During the winter months the funnel is removed, so that snow and sleet pass directly into the receiver and are recorded as equivalent rainfall. Total rainfall is one weather factor most commonly referred to in trying to characterize the corrosivity of an atmospheric exposure location. Dearden's work and the data to be discussed here indicate that total rainfall is of less importance than some other factors.

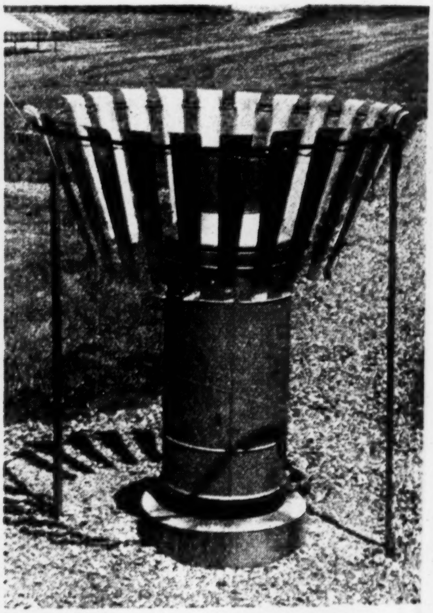

FIG. 3.—Recording Rain Gage.

The shelter containing the thermometer and hygrometer is shown in the lower right-hand corner of Fig. 1. These are standard instruments enclosed in a standard type shelter. The temperature sensitive element is a phosphor-bronze Bourdon tube filled with alcohol. The element is freely exposed outside the instrument case. The recording mechanism is clock-driven.

The hygrograph uses human hair as the moisture sensitive element. Although the hair element is quite sensitive to changes in relative humidity, it is not entirely satisfactory. In outdoor exposures the element becomes covered with dirt and soot. The hairs break, necessitating a complete overhaul of the instrument.

One anemometer and the wind vane are shown in Fig. 4, together with the shelter house for their recording instruments. This shelter also encloses the potentiometers for the pyrheliometer and the thermocouples attached to several specimens. The anemometer adjacent to the wind vane records wind velocity only. It is not activated by winds of less than 3 mph. and cannot be used to determine average wind velocities. A separate anemometer of the totalizing type is used for this purpose. All instruments are mounted fairly close to the ground surface near the corroding specimens.

A question frequently asked is: What is the maximum temperature reached by a specimen exposed to direct sunshine? The temperature would of course be determined by the intensity of the sunshine and the nature of the exposed surface, although other weather conditions also would have some effect in permitting a specimen to become hotter or to cool it. To obtain data on specimen temperatures, several materials were prepared with small copper-constantan thermocouples affixed to one surface. These were exposed with the thermocouples on the groundward side. Temperatures of the various specimens were recorded on a multiple point recording potentiometer. These data will not be used in this paper but rather a specific example will be given here. On August 18, 1947, at 1:20 p.m. the air temperature was 93 F., and the solar radiation was 1.24-g. cal. per sq. cm. per min. The temperature recorded for a 4 by 6-in. specimen of 18-8 stainless steel, No. 20 gage, with a No. 7 polish, was 122 F. A similar piece of stainless steel which had been chemically blackened reached 152 F. and a piece of corroded No. 16-gage iron 131 F.

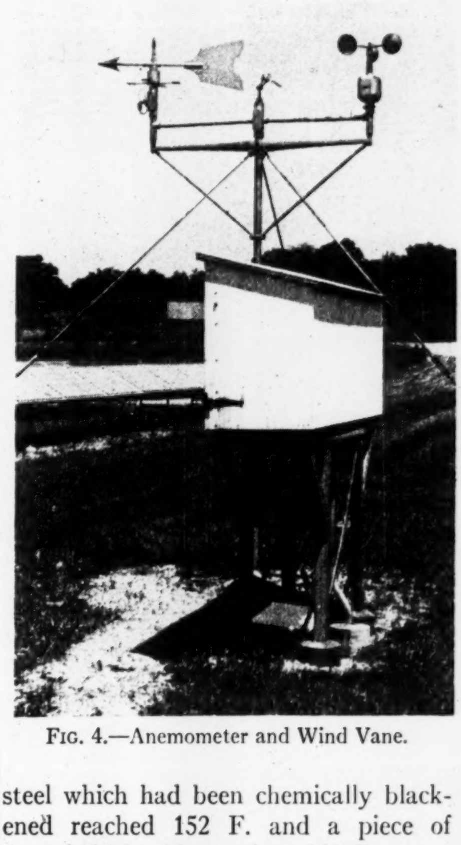

FIG. 4.—Anemometer and Wind Vane.

The last weather instrument to be described was designed to record the length of time that the surface of a specimen was wet, either by rain or dew. The active surface was a 4 by 6-in. pyrex glass plate with five parallel metallized strips on the skyward surface. Alternate strips were connected and a small potential applied. When the surface of the plate was wet, the decrease in resistance caused a thyratron tube to fire, actuating a relay connected to a recording mechanism. When the plate became dry, a second thyratron tube actuated a second relay and the record was discontinued.

This instrument worked reasonably well for several months. However, the small amount of current that flowed across the gaps when the plate was wet corroded the metallized strips. The dry residue of corrosion products continued to conduct enough current to prevent the second thyratron from discontinuing the record. This instrument has been redesigned to work using alternating instead of direct current. The new instrument appears to be working satisfactorily, although it has not been in use long enough to accumulate sufficient data for a proper evaluation. It is quite probable that the glass plate did not become wet or dry exactly at the same time as a specimen of zinc or iron; yet the record did provide some valuable data as will be shown later.

PLAN OF INVESTIGATION

This investigation was planned to cover a period of two years. Because of the great variation in weather over long periods of time, it was thought that the most valuable information would be obtained from exposures of short duration. Therefore, the basic exposure period was four weeks. The plan of exposure and removal of specimens was such that initial 28-day weight losses as well as accumulated weight losses would be available up to a maximum period of two years. Samples of five specimens each or iron and zinc were exposed. The test was started on Monday morning, April 15, 1946, and completed on Monday morning, April 12, 1948. More than 4000 individual 4 by 6-in. specimens were exposed.

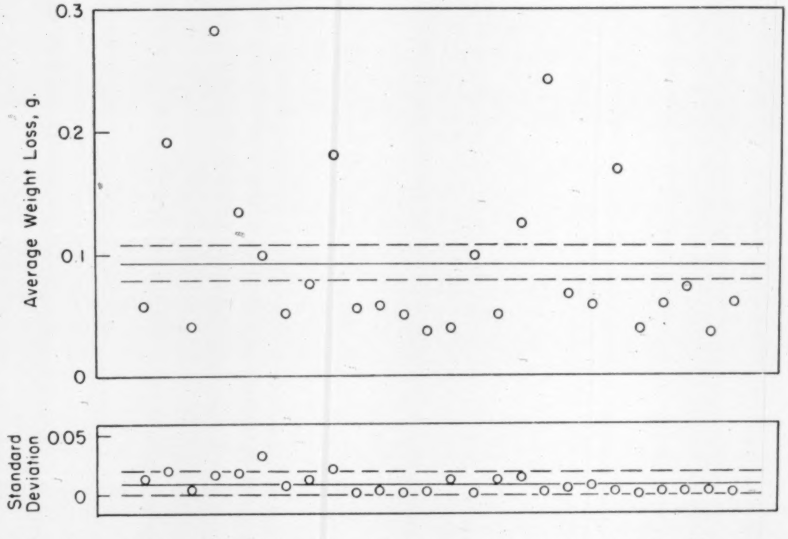

FIG. 5.—Control Chart of Weight Losses and Standard Deviations of 26 Samples of Sheet Zinc.

During the early planning of this investigation, there was some doubt about using sheet zinc as one of the test materials. Earlier experiences with sheet zinc exposed in a similar location has indicated that the weight loss for a 28-day period should be relatively small. Even so, zinc was included and the data from the sheet zinc tests have provided the subject matter for this discussion.

DATA

First removal of zinc showed a weight loss reasonably close to the anticipated value. The second set of specimens, however, lost more weight than had been expected. It soon became evident that the initial 28-day weight loss data from sheet zinc were very erratic, indicating that the initial corrosion rate varied over a wide range.

The initial 28-day weight loss data from the sheet zinc are shown in Fig. 5 and in Table I.

Weight losses are plotted consecutively and the average of the 26 samples is shown as a solid line at approximately 0.093 g. The 3σ limits, calculated as described in the A.S.T.M. Manual on Presentation of Data,[3] are drawn on either side of the average with a dashed line. It will be noted that only two of the 26 averages lie within these limits. The control chart for standard deviations is given in the lower part of Fig. 5. All standard deviations, except two, lie within the calculated limits.

Highest weight loss was 0.280 g. obtained in the 28-day period between July 8 and August 5, 1946. Lowest weight loss, 0.035 g., was obtained between February 16 and March 15, 1948. The ratio of maximum to minimum weight loss is 8 to 1.

TABLE I.—TWENTY-EIGHT DAY WEIGHT LOSSES AND STANDARD DEVIATIONS OF SHEET ZINC AND WEATHER DATA FOR THE EXPOSURE PERIODS.

Date Exposed	Average Weight Loss, g.	Standard Deviation $n = 5$	Average Wind Velocity, mph.	Average Relative Humidity, per cent	Average Temperature, deg. Fahr.	Total Rain, in.
April 15, 1946	0.056	0.012	4.9	78	53	3.4
May 13, 1946	0.190	0.020	5.2	81	61	5.5
June 10, 1946	0.038	0.003	3.9	83	70	5.2
July 8, 1946	0.280	0.016	2.8	80	72	1.7
August 5, 1946	0.134	0.018	3.4	78	65	2.7
September 2, 1946	0.098	0.033	2.9	74	64	0.9
September 30, 1946	0.050	0.008	3.0	73	54	2.0
October 28, 1946	0.075	0.012	4.2	78	47	2.0
November 25, 1946	0.180	0.021	4.2	80	36	3.8
December 23, 1946	0.054	0.001	5.3	88	33	4.4
January 20, 1947	0.057	0.003	7.7	79	29	1.9
February 17, 1947	0.050	0.002	6.7	81	27	0.7
March 17, 1947	0.036	0.003	6.9	76	43	3.8
April 14, 1947	0.039	0.003	5.3	79	51	6.5
May 12, 1947	0.099	0.013	4.2	84	65	12.7
June 9, 1947	0.049	0.002	3.2	80	71	4.1
July 7, 1947	0.125	0.014	3.4	83	71	6.4
August 4, 1947	0.242	0.015	2.4	88	77	1.8
September 1, 1947	0.067	0.005	3.0	83	66	2.8
September 29, 1947	0.059	0.006	2.8	80	61	0.3
October 27, 1947	0.169	0.008	4.6	84	43	3.9
November 24, 1947	0.038	0.004	4.7	82	30	1.2
December 22, 1947	0.060	0.002	4.9	89	27	2.3
January 19, 1948	0.073	0.004	3.9	88	20	3.4
February 16, 1948	0.035	0.004	5.8	86	35	2.0
March 15, 1948	0.060	0.003	5.8	89	52	9.4

Weight loss data for the iron samples exposed for 28-day periods are shown in Fig. 6. The average and 3 σ control limits are shown as in the previous figure. Notice that 23 of the 26 weight losses

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[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 33, Part I, p. 451 (1933); also issued as separate pamphlet, *STP No. 15 B.*

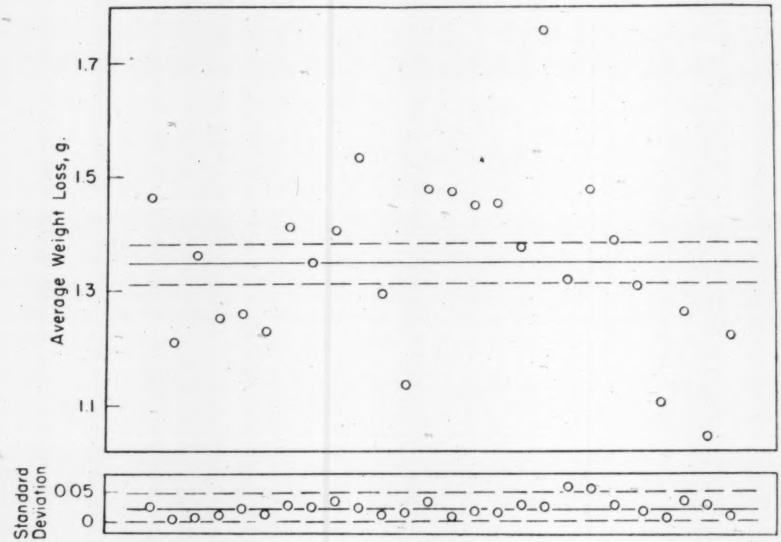

FIG. 6.—Control Chart of Weight Losses and Standard Deviations of 26 Samples of Iron.

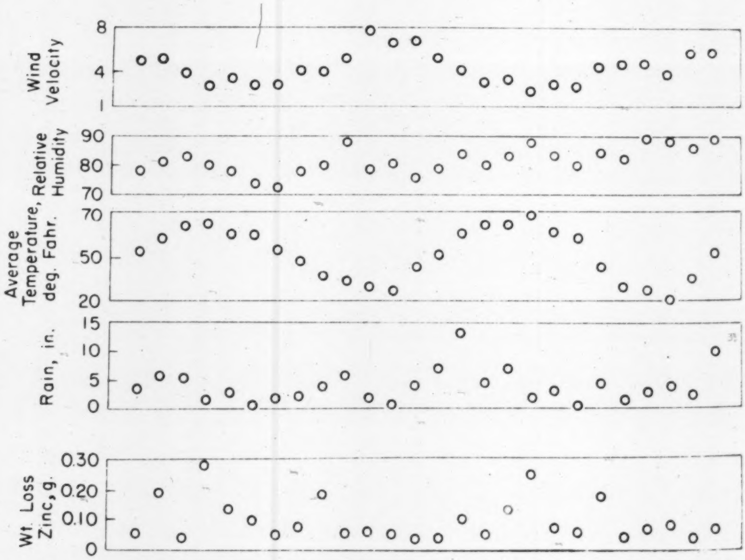

FIG. 7.—Weight Losses of 26 Samples of Sheet Zinc Together With Weather Variations for the Same Exposure Periods.

lie outside the control limits, while two of the standard deviations are outside the control limits for standard deviations. The highest weight loss of iron was 1.76 g. for the period August 4 to September 1, 1947. The lowest weight loss was 1.04 g. for the period February 16 to March 15, 1948. The ratio of maximum to minimum is 1.7 to 1.

The conclusion to be drawn from the data presented in Figs. 5 and 6 is that the samples are consistent within themselves but vary considerably one to the other because of variations in external conditions.

The consecutive 28-day weight losses for sheet zinc plotted against several weather variables are shown in Fig. 7. The data also are tabulated in Table I.

It will be noted that there is no apparent correlation between the weight loss data and any of the several weather data. However, with weight losses varying as much as 8 to 1, there should be some combination of weather factors that could be used to explain at least part of the variance.

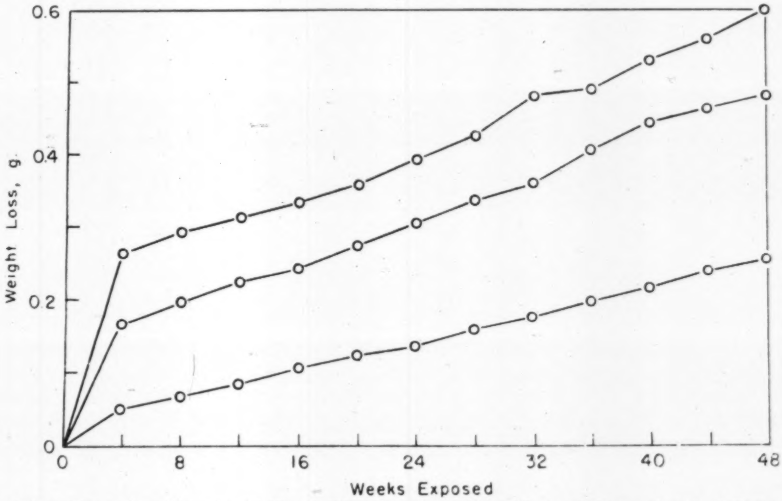

FIG. 8.—Time-Corrosion Curves of Sheet Zinc Showing that Rate of Corrosion is Affected by the Severity of Initial Attack.

Because of the great variation in weight loss from one sample of zinc to the next in the early part of the test, subsequent exposures were observed almost daily. It was noted that some samples appeared quite different from other. These differences became apparent within the first week of exposure. Some samples developed a peculiar spotted condition on the skyward surface. Others developed a uniform thin coating of corrosion products. It was found that those samples with the spotted condition corroded at a more rapid rate than the others, which led to the two most interesting observations in the test, noted below.

The first was that the initial attack on zinc affected its subsequent rate of corrosion. In Fig. 8 are shown time-corrosion curves of several samples exposed at different times. The upper curve represents the average weight loss of two samples of zinc that showed high 28-day weight losses. The lower curve is the average of five samples of zinc that showed low initial weight losses

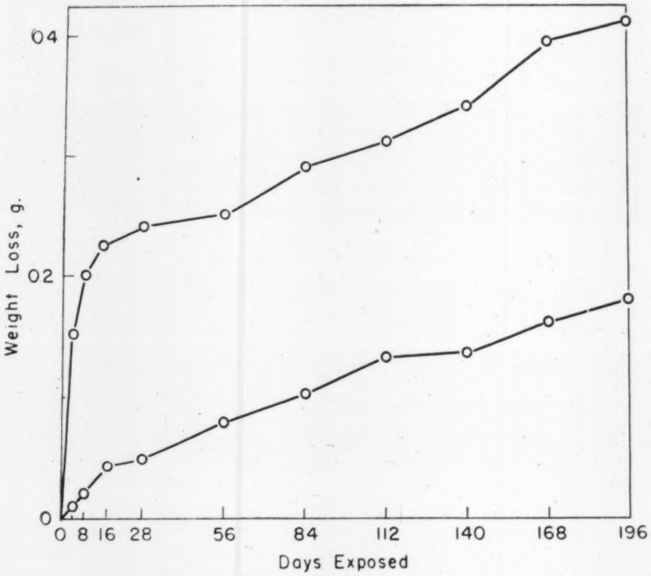

FIG. 9.—Time-Corrosion Curves of Two Samples of Sheet Zinc Showing High and Low Initial Rates of Corrosion.

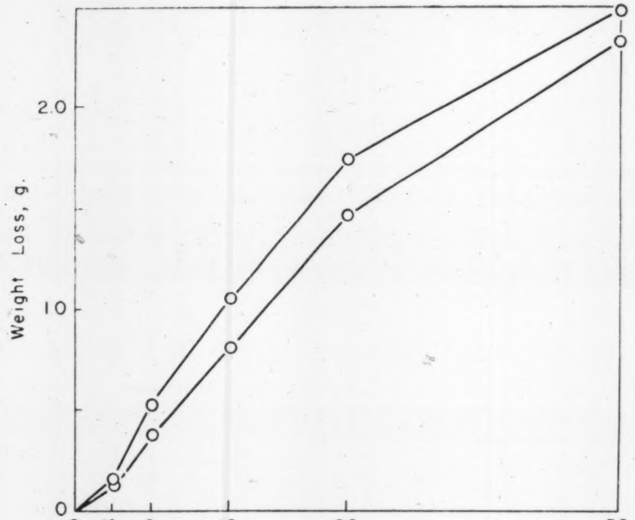

FIG. 10.—Initial Time-Corrosion Curves of Two Samples of Iron Exposed on Different Dates. Note Similarity of Corrosion Rates.

The center curve is the average of several samples showing initial weight losses of intermediate values. It will be noted that the slopes of the curves after the initial 28-day period are different. Samples that suffered the more severe attack initially continued to corrode at a higher rate than those which were less severely corroded initially. Those samples which initially corroded at an intermediate rate very nearly parallel those starting at a higher rate.

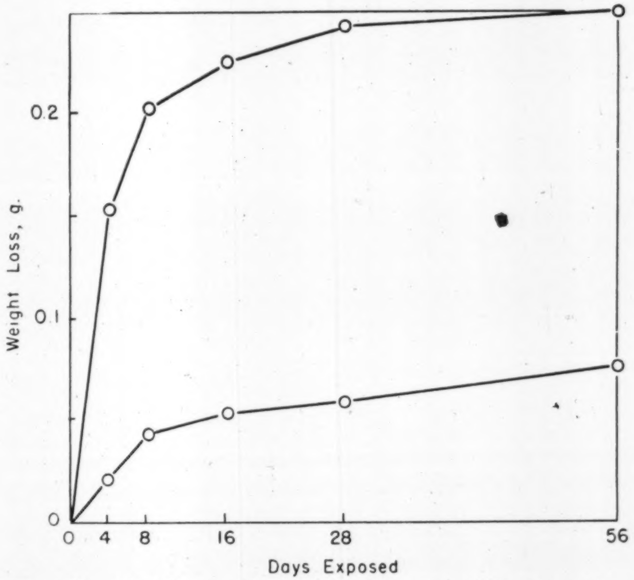

FIG. 11.—Initial Time-Corrosion Curves of Two Samples of Sheet Zinc Exposed on Same Dates as Irons Shown in Fig. 10. Note Great Dissimilarity of Corrosion Rates.

In order to determine the effect of the first few days of exposure, a number of samples were exposed for periods of 4, 8, and 16 days. The time-corrosion curves of two samples of zinc attacked at different rates are shown in Fig. 9. The sample represented by the lower curve was exposed February 17, 1948; the sample represented by the upper curve was exposed August 4, 1947. In the first four days the latter sample lost 15 times as much weight as the former. This ratio decreased to five times at 28 days, although the numerical difference between the weight losses of the two samples continued to increase.

The second observation of interest was that the conditions of weather which resulted in severe or mild initial attack on sheet zinc did not have the same effect on iron. Comparative time-corrosion curves of samples of iron exposed on different dates are shown in Fig. 10. In Fig. 11 are shown time-corrosion curves of samples of sheet zinc exposed on the same dates as the iron samples of Fig. 10. Note that there is only a slight difference in the corrosion rates of the two samples of iron, but there is a very large difference in the corrosion rates of the two samples of zinc. This is an excellent group of samples to demonstrate that the same weather conditions are apt to produce vastly different initial corrosion rates on zinc and iron.

DISCUSSION OF DATA

While a detailed study of the effect of weather on initial weight losses has been made for the samples of sheet zinc included in this test, no analysis of the weight loss data from the short exposures of iron has been made up to this time.

Early observations of the behavior of zinc samples during the first few days of exposure indicated that the probable rate of attack for the first four weeks could be estimated from the appearance of the samples during the first week of exposure. If these observations were correct, then it should be possible to explain some of the variation between different exposures on the basis of the variations in weather conditions during the first few days of exposure.

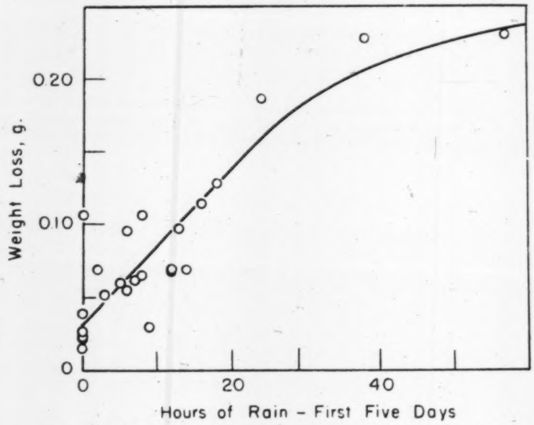

FIG. 12.—Weight Loss of Sheet Zinc *versus* Hours of Rainfall for the First Five Days of Exposure.

Adjusted to Average Values of Hours of 100 per cent Relative Humidity for Five Days, Hours Rainfall After the First Five Days, and Hours of 100 per cent Relative Humidity After the First Five Days.

Therefore, the 28-day weight losses on the zinc samples were studied with relation to the weather during the first week of exposure. It was found that a correlation did exist between the 28-day weight losses and the number of hours wet, as indicated by the wet or dry condition of the glass plate, for the first few days' exposure. The record of wet and dry condition provided by the "wet meter" was not perfect because there was some question whether the glass plate became wet or dry in the same manner as a corroded metal specimen. It probably did not. Furthermore, the equipment did not provide a record throughout the test for reasons which were described earlier.

In order to obtain data for the entire period of test, which would be comparable to that recorded by the wet meter, the various weather records were studied. From the rain-gage chart the number of hours' duration of rainfall could be estimated. The hygrometer record gave the number of hours that the relative humidity was at or near 100 per cent. Observations made late at night and early in the morning indicated that the condensation of dew on the specimens and its subsequent evaporation followed the relative humidity curve very closely. The combination of these data gave results in close agreement with the estimates of hours wet as recorded by the wet meter. These data were then used to study the variations in initial 28-day weight loss of sheet zinc.

A multiple correlation study of several variables is a slow and tedious procedure by the usual methods of correlation analysis. Ezekiel (5) describes a method of multiple correlation analysis by a graphical procedure. Taylor (6) has discussed the practical application of this procedure. The first step in this method of analysis consists of making a simple correlation between observed weight loss and each of the variables. A line is drawn to represent the effect of the variable on weight loss. From this line the effect of that variable is estimated, and the weight losses are corrected to an average value of the variable. Corrected weight losses are then plotted against another variable, and a similar correction is made. After several approximations, the shape of the curve becomes static. From the final curves the effect of each variable, independent of the others, is evident.

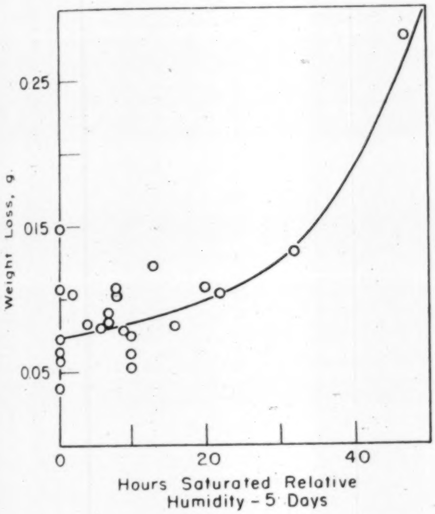

FIG. 13.—Weight Loss of Sheet Zinc *versus* Hours of 100 per cent Relative Humidity for the First Five Days.

Adjusted to Average Values of Hours Rainfall for the first Five Days and Last Twenty-three Days and Hours of 100 per cent Relative Humidity After the First Five Days of Exposure.

The 28-day weight losses of the sheet zinc were studied in that manner with relation to: (1) the number of hours of rain and (2) the number of hours that the relative humidity approached saturation during the first five days' exposure. Later the number of hours of rain and the number of hours the relative humidity was at or close to 100 per cent

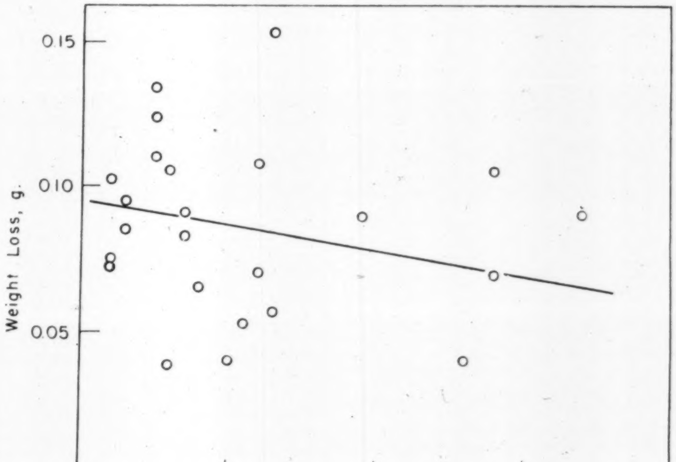

FIG. 14.—Weight Loss of Sheet Zinc *versus* Hours of Rainfall After the First Five Days.

Adjusted to Average Values of Hours of Rainfall and 100 per cent Relative Humidity for the First Five Days and Hours of 100 per cent Relative Humidity after the First Five Days.

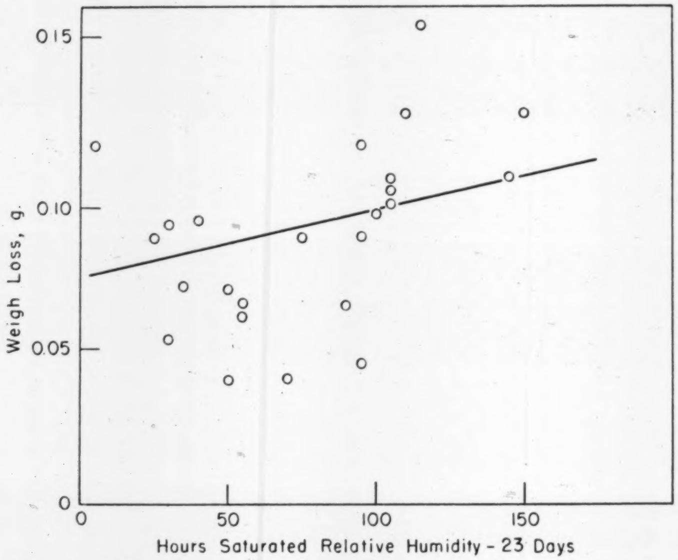

FIG. 15.—Weight Loss of Sheet Zinc *versus* Hours of 100 per cent Relative Humidity After the Firs Five Days.

Adjusted to Average Values of Hours of Rainfall and 100 per cent Relative Humidity for the First Five Days and Hours of Rainfall after the First Five Days.

TABLE II.—COMPUTATION OF FUNCTIONAL VALUES CORRESPONDING TO INDEPENDENT VARIABLES, OF THE ESTIMATED VALUE OF X_0, AND THE RESIDUAL, FOR EACH AVERAGE VALUE OF X_0.

$\Sigma f(X) = f(X_1) + f(X_2) + f(X_3) + f(X_4)$

X_0' = Estimated weight loss

X_0 = Observed weight loss

X_1 = Hours of rain during first 5 days of exposure

X_2 = Hours relative humidity at 100 per cent during first 5 days of exposure

X_3 = Hours of rain during last 23 days of exposure

X_4 = Hours relative humidity at 100 per cent during last 23 days of exposure

X_1	X_2	X_3	X_4	$f(X_1)$	$f(X_2)$	$f(X_3)$	$f(X_4)$	$\Sigma f(X)$	$\Sigma f(X) + a = X_0'$	X_0	$X_0 - X_0'$
8	0	136	38	0.074	0.073	0.072	0.081	0.300	0.041	0.056	0.015
57	0	62	32	0.234	0.073	0.084	0.080	0.471	0.212	0.190	−0.022
9	10	48	94	0.080	0.083	0.087	0.093	0.343	0.084	0.038	−0.046
6	47	26	117	0.063	0.260	0.091	0.098	0.512	0.253	0.280	0.027
8	22	23	151	0.074	0.101	0.092	0.105	0.372	0.113	0.134	0.021
0	32	12	104	0.031	0.134	0.093	0.095	0.353	0.094	0.098	0.004
0	7	33	105	0.031	0.079	0.090	0.095	0.295	0.036	0.050	0.014
12	10	40	92	0.095	0.083	0.088	0.093	0.359	0.100	0.075	−0.025
38	8	169	26	0.206	0.080	0.066	0.078	0.430	0.171	0.180	0.009
13	0	139	56	0.100	0.073	0.072	0.085	0.330	0.071	0.054	−0.017
5	20	29	34	0.058	0.098	0.090	0.080	0.326	0.067	0.057	−0.010
0	0	65	6	0.031	0.073	0.084	0.074	0.262	0.003	0.050	0.047
14	0	130	72	0.106	0.073	0.073	0.088	0.340	0.081	0.036	−0.045
12	0	56	48	0.095	0.073	0.085	0.083	0.336	0.077	0.039	−0.038
18	7	93	48	0.127	0.079	0.079	0.083	0.368	0.109	0.099	−0.010
3	4	17	76	0.048	0.076	0.092	0.088	0.304	0.045	0.047	0.002
16	6	15	100	0.116	0.078	0.093	0.094	0.381	0.122	0.125	0.003
6	9	17	95	0.063	0.082	0.092	0.093	0.330	0.071	0.067	−0.004
0	10	11	43	0.031	0.083	0.093	0.103	0.310	0.051	0.059	0.008
24	13	35	28	0.159	0.087	0.089	0.078	0.413	0.154	0.169	0.015
7	0	35	53	0.068	0.073	0.089	0.084	0.314	0.055	0.038	−0.017
0	8	31	93	0.031	0.080	0.090	0.093	0.294	0.035	0.060	0.025
2	2	62	108	0.041	0.075	0.084	0.096	0.296	0.037	0.073	0.036
0	16	64	107	0.031	0.090	0.084	0.096	0.301	0.042	0.035	0.007

during the last 23 days of exposure were studied also.

During the detailed study of the various data, it was found that two of the 26 samples of zinc corroded at rates that could not be explained by any of the variables studied. These two samples were not considered in any of the subsequent analyses.

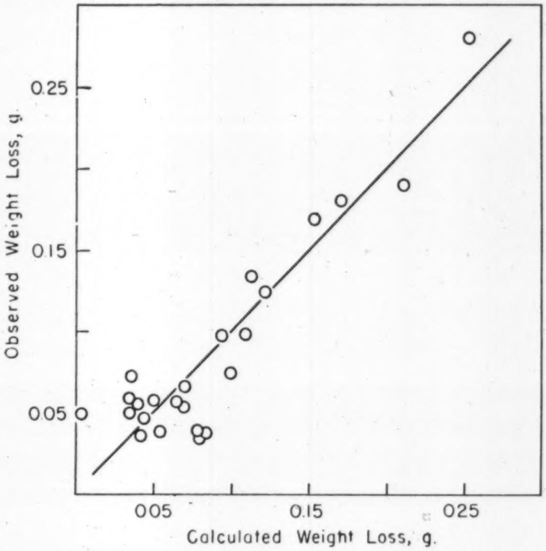

FIG. 16.—Observed Weight Losses of Sheet Zinc *versus* Calculated Weight Losses.

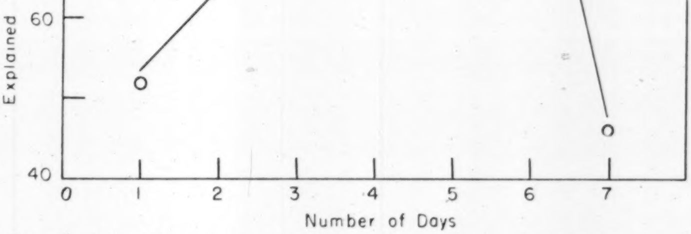

FIG. 17.—Per Cent Explained Variance of 24 Samples of Sheet Zinc *versus* Weather Conditions During the First Week of Exposure.

In Fig. 12 is shown the effect of the number of hours of rain on the weight loss of zinc during the first five days. These data have been corrected to average values of the other variables, so the relationship shown is that of rain only.

Figure 13 reveals the effect of the number of hours of relative humidity of 100 per cent for the first five days. This curve also has been adjusted to average values of the other variables, which means the effect is one of humidity alone. It will be noted that increased time of exposure to conditions leading to condensation on the specimens results in greater weight loss of sheet zinc.

Figure 14 shows the effect of the number of hours of rainfall after the first five days of exposure.

Figure 15 shows the effect of 100 per cent relative humidity after the first five days. It will be noted that these variables are of considerably less importance than rain and 100 per cent relative humidity during the first five days.

The independent variables studied and the computation of the functional values are shown in Table II. The tabulation and calculations follow the methods described by Ezekiel.

The plot of the calculated *versus* observed weight losses is shown in Fig. 16.

If the calculated values were in perfect agreement with the observed values, all points would lie on a straight line inclined at an angle of 45 deg. Deviation of points from this 45-deg. line is a measure of the extent to which the observations are not explained by the relations shown in Figs. 12, 13, 14, and 15. By calculation, 84 per cent of the total variance of the 28-day weight losses of 24 samples of sheet zinc is explained.

For convenience in plotting the data, the averages of each sample of five specimens were used. If, for the final estimate, the weight losses of the 120 specimens were used, then the explained variance decreases to 82 per cent. With so large a sample the observed correlation is not greatly different from the probable minimum correlation of the universe, and the results are highly significant.

Previous discussion has centered on the effect of the weather during the initial five-day period on 28-day weight losses. Similar correlation analyses were made of the effect of weather during 1, 2, 3, 4, 5, 6, and 7-day periods. Results of these analyses are shown in Fig. 17. Observe that any of these time periods explains more than 40 per cent of the variance within the group of zinc samples exposed for 28 days. However, the weather during the first 4, 5, or 6 days explains more than 80 per cent of the variance within the group of samples.

The significant part of this study is that more than three fourths of the variation found in the initial weight losses of sheet zinc can be explained on the basis of certain weather phenomena for the first few days of exposure. The rest of the variation may be attributed to other factors, such as variations in atmospheric contamination, temperature, sunshine, wind direction and velocity, and factors still unknown.

SUMMARY

Summarizing, it has been shown that the initial rate of corrosion observed on sheet zinc exposed for short periods of time varied considerably. Weather conditions that produced these great variations in the behavior of zinc did not result in similar variations in the initial corrosion rate of iron. The rate of corrosion of zinc after the initial exposure was affected by the severity of the initial attack. Finally, the great variation found in the initial 28-day weight losses of 26 samples of zinc exposed consecutively has been partly explained on the basis of four factors of weather:

1. The number of hours of rainfall during the first five days of exposure,

2. The number of hours of high relative humidity conducive to condensation of dew during the first five days of exposure,

3. The number of hours of rainfall after the first five days of exposure, and

4. The number of hours the relative

humidity was near 100 per cent after the first five days of exposure.

Acknowledgments:

I wish to express my appreciation for valuable assistance received during this study. Mr. H. H. Lawson prepared, cleaned and weighed all the many specimens involved in the exposures. Mr. C. R. Taylor and Mr. Arthur Woods offered many suggestions and considerable help in the details of the statistical analysis of the data.

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(6) C. R. Taylor, "Graphical Correlation—Its Application to Steel Mill Problems," *Iron Age*, November 6, 1947, p. 78.

DISCUSSION

Mr. H. R. Copson (*presented in written form*).[1]—There are two features of the weather measurements described by O. B. Ellis which are particularly commendable. First weather conditions were measured at the exact place and time that weight losses were determined. The importance of doing this can be illustrated by recalling the difference that elevation can make in such things as wind velocity, fog, rate of drying, and length of time wet.

Second, attempts were made to determine conditions at the metal surface. A difficulty here, as was recognized by Ellis, is that each specimen has its own individual characteristics. Thus it was shown that metal temperatures might be as much as 60 F. above air temperatures, but it is obvious that actual differences will depend on the character of the metal surface, on the color, texture, and thickness of corrosion products, and on accumulations of dirt. The length of time wet of individual specimens is influenced by similar factors.

These comments are made to emphasize the difficulties involved in getting applicable weather data. Without such data good correlation with weight losses can hardly be expected.

One important factor which was not measured is atmospheric pollution. This may be the reason no clear correlation was found between atmospheric conditions and the weight losses of iron. The estimation of atmospheric pollution is not easy. It requires detailed knowledge of the concentration and variation of corrosive gases such as sulfur dioxide and of solids such as chlorides, sulfates, and other active materials. It seems evident that pollution will not be constant but will vary with industrial activity, with rainfall, humidity, wind direction, wind velocity, and other atmospheric conditions. Further complications arise because dew may contain more sulfur dioxide than rain, and because dew which forms on rusting iron may contain more sulfur dioxide than dew which forms on glass.

The change in the corrosion rate of zinc near the start of the tests must mean that a protective film is being built up. Yet after this initial period has passed, the corrosion rate is substantially constant with time even though the corrosion products continue to thicken. Evidently the outer thicker layers of corrosion product are not protective. In order to control the subsequent corrosion rate, the first formed protective inner layer must persist. This raises a question as to the mechanism by which corrosion is taking place through this protective film without at the same time destroying it.

Ellis correlated the protective character of the first corrosion product with the humidity and hours of rain. If these were the sole factors, it would seem that as the initial exposure period was made shorter atmospheric conditions would become more uniform and the per cent explained variance would increase. This was not the case. As the initial period increased, the per cent explained variance increased steadily from 52 per cent at one day to 84 per cent at five days, and then decreased again. Apparently it took time for the protective film to build up. After about five days its character was set, and subsequent events had little influence on it.

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[1] Research Chemist, The International Nickel Co., Inc., Research Lab., Bayonne, N. J.

If this interpretation is correct, it raises some interesting speculation. Why not control conditions so as to put a good protective film on zinc before exposing it outdoors? If subsequent events then have little effect, it should be possible to obtain similar low rates of corrosion regardless of atmospheric conditions. It would be interesting to transfer specimens with a good protective coating from Middletown to other normally more corrosive (or less corrosive) locations and determine whether the corrosion rate remains constant.

In inclined exposures of the type described, zinc usually corrodes faster on the skyward surface than on the groundward. It would be interesting to know if this was the case in these tests. If so, a more protective film must have formed on the groundward surface. This surface is more sheltered, receives less rain, and is apt to remain damp longer, but it is difficult to explain the difference in behavior on the basis of the correlations in the paper. Of course from a statistical standpoint it would have been more ideal to have dealt with the two surfaces separately.

MR. F. L. LAQUE.[2]—I wish to commend Mr. Ellis for the tremendous amount of work that he has done, not only in carrying out a laborious test program, but subjecting his results to what was evidently a rather detailed and careful analysis. It is that kind of work that will improve the ability to apply the results of atmospheric corrosion tests.

Having in mind the use by Subcommittee VII on Weather of Committee B-3 of both steel and zinc for measuring differences in corrosivity of atmospheres in different places—and the fact that the British Iron and Steel Institute have used both ingot iron and zinc for similar purpose, and I understand, now, have decided to concentrate their attention on zinc—I am wondering if Mr. Ellis has formed an opinion as to which of those two metals over a one-year test period would be least sensitive to the variation in conditions in the early stages of test, and thereby reflect more clearly actual differences in over-all corrosivity of locations rather than the conditions that happened to exist at the time the tests were started at these different places.

MR. O. B. ELLIS (*author*).—Mr. LaQue's questions should be answered in the reverse order. It is obvious that zinc is extremely susceptible to initial conditions of weather and, therefore, would be less acceptable as a calibration metal for a long period of exposure.

The attempt that has been made to study the iron data in a manner similar to that shown for the zinc has met with complete and utter failure. It has not been possible to pick out any assortment of variables that will correlate with the variations shown by the iron samples.

Figure 8 shows time-corrosion curves for samples of zinc up to a period of approximately one year. These samples indicate that the rate of attack during the initial exposure period has an influence on the final rate of corrosion. Samples with low corrosion rates for the first 28 days show a lower rate at one year than similar samples which showed high initial rates of attack. Therefore, it is evident that zinc is not a satisfactory metal to be used for atmospheric calibration tests. At this time, it is not possible to state that iron is better or worse.

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[2] In Charge of Corrosion Engineering Section, Development and Research Div., The International Nickel Co., Inc., New York, N. Y.

MR. C. P. LARRABEE.[3]—I wonder if the question of pollution would not depend upon the direction of the wind? The atmospheric test plot at Middletown is two or three miles from the plant, and on days that the wind is blowing from the plant, the atmosphere would probably be much more polluted than on days when the wind blows from any other direction, as the plant is probably the largest source of atmospheric contamination.

MR. O. B. ELLIS *(author's closure)*.—The question of wind velocity was not mentioned in this paper. The variations in wind direction as well as wind velocity were so great that at the time the study was made, it was not possible to find any way of correlating these variables with the weight loss data.

Atmospheric pollution, which is very diffcult to measure, also must be an important factor in the final corrosion rate.

It is well known that iron oxide has a great affinity for sulfur compounds. There is a possiblity that a corroded iron specimen may continue to absorb sulfur dioxide from the atmosphere even during those periods when the specimen appears to be dry.

Experiments that have been made previous to this work have shown that the rust on an iron specimen is never completely dry. The rust contains approximately 13 per cent of water which will vary 1 or 2 per cent depending on conditions of atmospheric humidity. Therefore, the problem is far more complicated with iron that it appears to be with zinc.

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[3] Research Lab., Carnegie-Illinois Steel Corp., Vandergrift, Pa.

REPORT OF COMMITTEE B-4
ON
ELECTRICAL HEATING, RESISTANCE AND RELATED ALLOYS*

Committee B-4 on Electrical Heating, Resistance and Related Alloys held three meetings since its previous report: in New York City, N. Y., on June 9 and 10, 1948; in Cambridge, Mass., on October 13 and 14, 1948, and in Philadelphia, Pa., on March 2 and 3, 1949.

During the year the committee has lost the services, by retirement, of P. H. Dike who, for the past ten years, has been chairman of Subcommittee II on Electrical Tests, and of W. A. Gatward, another long-time member, chairman of Subcommittee I on Electrical Heating Materials, who resigned from the committee.

The committee now consists of 71 members, of whom 29 are classified as producers, 37 as consumers, and 5 as general interest.

Recommendations Accepted by the Administrative Committee on Standards

Subsequent to the 1948 Annual Meeting, Committee B-4 presented to the Society, through the Administrative Committee on Standards, a new Tentative Recommended Practice for Cathode Melt Prove-in Testing which was accepted by the Committee on Standards on May 2, 1949, and is designated B 238 - 49 T.[1]

Adoption of Tentatives as Standard

The committee recommends that the following three tentatives be approved for reference to letter ballot of the Society for adoption as standard without revision:

Method of Test for Resistivity of Metallically Conducting Resistance and Contact Metals (B 63 - 48 T),[2]

Method for Life Test of Electrical Contact Materials (B 182 - 46 T),[3] and

Method of Test for Diameter by Weighing of Fine Wire Used in Electronic Devices and Lamps (B 205 - 45 T).[3]

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

Activities of Subcommittees

Subcommittee I on Electrical Heating Materials (C. L. Raynor, chairman).—Work on refinements in the Method of Accelerated Life Test for Metallic Materials for Electrical Heating (B 76 - 39) is being done at Massachusetts Institute of Technology. Progress on this work, which includes the quantitative effect of humidity on the life of wire at high temperature, will be reported to Committee B-4 at its next meeting.

Subcommittee II on Electrical Tests (J. L. Thomas, chairman) is recommending the adoption as standard of Method B 63, previously mentioned.

Subcommittee V on Wrought and Cast Alloys for High-Temperature Use (R. D. Van Nordstrand, chairman) is continuing tests in the standard A.S.T.M. furnace to ascertain the effects of various atmospheres on surface and subsurface conditions of the metal. Magnetic readings are being reviewed as related to "green rot" or structural changes. The subcommittee is also working on the development of a test method to determine oxidation resistance of wrought cast alloys at high temperatures. Exploratory work has been done and preparations are being made to run trials in the furnace developed for testing materials in gas atmospheres in accordance with the Tentative Method of Test for Effect of Controlled Atmospheres Upon Alloys in Electric Furnaces (B 181 - 43 T).

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] 1949 Book of A.S.T.M. Standards, Part 2.

[2] 1948 Supplement to Book of A.S.T.M. Standards, Part I-B.

[3] 1946 Book of A.S.T.M. Standards, Part I B

[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

Subcommittee VII on Thermostat Metals (P. H. Brace, chairman) is conducting investigations of significant properties for development of test methods of thermostat metals. Currently the relation of hardness test method agreements *versus* load is under consideration; also extension of hardness test methods to thin thermostat metals. Recently a program has been started on invar with particular reference to methods of test using interferometer, steam and water jacket test, and the use of the automatic recorder. Specifications will be considered after the test methods have been reviewed and completed.

Subcommittee VIII on Metallic Materials for Radio Tubes and Incandescent Lamps (S. A. Standing, chairman) is recommending adoption as standard of Method B 205, previously mentioned.

Section A on Cathode (T. H. Briggs, chairman) has dealt with the many problems pertinent to nickel cathode material for electronic tubes and has made good progress. Physical testing specifications have been reviewed, improved, and brought up to date. The bulk of the effort, however, has been in defining suitable testing methods and specifications for cathode material. Aside from physical testing, this effort has involved designing a standard diode tube as a means of testing and development of chemical methods to aid in the definition of suitable material. In addition studies on the effects of various impurities in cathode nickel have been undertaken on a broad scale. Currently, this group has sponsored the Tentative Recommended Practice for Cathode Melt Prove-In Testing (B 238 - 49 T) and has recently completed a Proposed Tentative Specification for Circular Nickel Cathode Sleeves for Electronic Devices, now being circulated for committee letter ballot. Its activities have been linked with that of Committee E-3 on Chemical Analysis of Metals to assist in penetrating the problems of chemical analysis. It is anticipated that activities will continue at a high rate for the forthcoming year.

Section C on Tungsten Wire (D. H. Wamsley, chairman) is concerned with developing methods of test and specifications with the initial task centered around the sag properties of this material. Section D on Particle Size and Density of Powder (Stanton Umbreit, chairman) is at present confining its investigation to a new testing instrument for powders commonly used in the electronic tube and lamp fields.

More recently, Subcommittee VIII has been approached by Committee C-6 of the Joint Electron Tube Engineering Council to assist in formulating methods of test and specifications for metal-to-glass seals, considering, in this instance, relatively large metallic cross-sections and using as a basis the present A.S.T.M. Tentative Method for Measuring Residual Stress in Cylindrical Metal-to-Glass Seals (B 218 - 47 T).

Subcommittee IX on Methods of Test for Alloys in Controlled Atmospheres (P. H. Brace, chairman) is cooperating with Subcommittee V in tests in various laboratories using processes developed with the aid of Method B 181 - 43T. Inter laboratory checks are being made on the effects of various types of atmospheres.

Subcommittee X on Contact Materials (F. E. Carter, chairman) recommended the adoption as standard of Method B 182, previously mentioned. During the past year Section A on Life Tests has been actively engaged in experimentation on the factors affecting the surety of making circuit, such as maximum breakdown voltage and the variation of resistance with current. At present a test method is in preparation.

Section B on Physical Properties has been active on hardness determination of contact materials. Work is in progress on a proposed method of test which involves a study of the implications of the hardness of thermostat metals. Section C on Standardization of Contact Forms and Sizes is revising present standards in the light of field difficulties.

This report has been submitted to letter ballot of the committee, which consists of 71 members; 66 members returned their ballots, of whom 60 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

S. A. STANDING,
Chairman.

F. E. BASH,
Secretary.

EDITORIAL NOTE

On June 24, 1949, the Administrative Committee on Standards accepted the recommendation of Committee B-4 that the Specifications for Circular Cross-Section Nickel Cathode Sleeves for Electronic Devices be approved for publication as tentative. The new tentative specifications appear in the 1949 Book of A.S.T.M. Standards, Part 2, bearing the designation B 239 – 49 T.

REPORT OF COMMITTEE B-5

ON

COPPER AND COPPER ALLOYS, CAST AND WROUGHT*

Committee B-5 on Copper and Copper Alloys, Cast and Wrought, held two meetings during the year: at Philadelphia, Pa., on November 5, 1948, and at Washington, D. C., on March 11, 1949. At these sessions the Advisory Committee and Subcommittees W-1, W-2, W-3, W-4 and G-3 also met. Subcommittee G-1 met at Philadelphia, Pa., and Subcommittee F-1, at Washington, D. C.

During the year 16 members were added to the committee and there were 14 removals. At the present time the committee consists of 139 members, of whom 120 are voting members; 52 are classified as producers, 46 as consumers, and 22 as general interest members.

RECOMMENDATIONS AFFECTING STANDARDS

The committee is submitting revisions in 25 tentative specifications, revisions in 35 standards for immediate adoption, tentative revisions in 5 standards, the adoption of one tentative as standard, and the adoption of 5 tentative revisions as standard. The standards and tentatives affected, together with the revisions recommended, are given in detail in the Appendix.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[1]

ACTIVITIES OF THE ADVISORY COMMITTEE

The following revisions in the regulations of the committee were approved by letter ballot:

Article V, Meetings.—Insert a new Section 6 to read as follows renumbering the present Section 6 as Section 7:

Sec. 6.—Any application for a proposed new standard or tentative or a substantial revision of an existing standard or tentative shall be addressed in writing to the chairman of the appropriate subcommittee with copies to the chairman and to the secretary of Committee B-5. Before such application may be considered, it shall be supported by appropriate technical and commercial qualifying data.

The Advisory Committee prepared the standard section on significance of numerical limits being recommended for incorporation in the various material specifications of the committee.

ACTIVITIES OF SUBCOMMITTEES

The following is the report of the several subcommittees during the year. The actions are given in detail in the Appendix.

Subcommittee W-1 on Plate, Sheet and Strip (R. A. Frye, chairman, S. A. Rosecrans, secretary) recommended that revisions be incorporated in 11 tentative specifications: B 19, B 36, B 121, B 122, B 129, B 130, B 131, B 152, B 169, B 194, and B 195. Revisions for immediate adoption were recommended in 6 standard specifications: B 11, B 96, B 97, B 100, B 103, and B 171.

A task group (W. D. France, chairman) prepared the revisions on sampling for chemical analysis in plate, sheet, and strip specifications. A task group (J. F. Klement, chairman) prepared requirements for alloy D to be incorporated in Specifications B 169.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

Among the subjects being studied by the subcommittee are the addition of sawed bar to plate specifications, the revision of copper limits for alloys Nos. 4 and 6 of Specifications B 121, the revision of requirements for mechanical properties in Specifications B 194 and B 195, the addition of alloy B2 of Specifications B 139 to Specifications B 103, and the use of Rockwell hardness information as a mandatory requirement.

Subcommittee W-2 on Rods, Bars and Shapes (J. D. MacQueen, chairman) recommended that revisions be incorporated in 7 tentative specifications: B 21, B 133, B 139, B 150, B 151, B 187, and B 196. Revisions for immediate adoption were recommended in 6 standard specifications: B 12, B 16, B 98, B 124, B 138, and B 140. Tentative revisions were recommended in 5 standard specifications: B 12, B 16, B 98, B 138, and B 140. Adoption as standard was recommended for tentative revisions of 5 standard specifications: B 12, B 16, B 98, B 138, and B 140.

A task group (V. P. Weaver, chairman) prepared the revisions of elongation requirements in rod and bar specifications. A task group (G. Williams, Jr., chairman) prepared the revision of chemical limits for alloy No. 11 in Specifications B 124. A task group (H. C. Ashley, chairman) prepared the revisions of Specifications B 12 and B 187 to include reference to the applicable types of copper in Classification B 224. A task group (H. C. Ashley, chairman) prepared the revisions on the requirements for sampling for chemical analysis. A task group (R. A. Frye, chairman) prepared revisions in straightness requirements in Specifications B 187. A task group (B. J. Sirois, chairman) recommended the deletion of bend tests in rod and bar specifications. A task group (G. Williams, Jr., chairman) prepared requirements for soft temper type A rods and bars in Specifications B 138.

Among the subjects being considered in the subcommittee are the inclusion of additional size ranges in Specifications B 133 and the collection of Rockwell hardness data in anticipation of the future inclusion of such requirements in rod and bar specifications.

Subcommittee W-3 on Wire and Wire Rod (B. J. Sirois, chairman) recommended that revisions be incorporated in 3 tentative specifications: B 159, B 197, and B 206. Revisions for immediate adoption were recommended in 2 standard specifications: B 99 and B 134.

A task group (W. D. France, chairman) prepared the revisions for sampling for chemical analysis in wire specifications.

The subcommittee is studying the possible revision of requirements for tensile strength and elongation in Specifications B 197.

Subcommittee W-4 on Pipe and Tube (Alan Morris, chairman, R. S. Pratt, secretary) recommended that revisions be incorporated in 3 tentative specifications: B 75, B 135, and B 188. Revisions for immediate adoption were recommended in 7 standard specifications: B 13, B 14, B 42, B 43, B 68, B 88, and B 111.

A task group (H. C. Ashley, chairman) prepared the revisions in applicable pipe and tube specifications on the inclusion of the applicable types of copper in Classification B 224. A task group (H. C. Ashley, chairman) prepared the revision of requirements for sampling for chemical analysis.

Among the subjects under consideration in the subcommittee are the development of requirements for automotive and refrigeration service tube, and revision of dimensional tolerances in Specifications B 111. The temper requirements of Specifications B 75 are being reviewed as to their adequacy.

Subcommittee F-1 on Castings, and Ingots for Remelting (G. H. Clamer, chairman, C. S. Cole, secretary) recommended the revision of Recommended Practice B 208. Revisions for immediate adoption were recommended in 14 standard specifications: B 30, B 61, B 62, B 66, B 67, B 132, B 143 to B 149, inclusive, and B 198. With minor revisions specifications B 22 were recommended for adoption as standard.

A task group (C. S. Cole, chairman) which had been working on the problem for the past two years prepared revisions in Recommended Practice B 208.

The subcommittee feels that the revision of B 208 will be a helpful first step in clarifying the test bar problem but calls attention to the need for an accumulation of engineering design data on copper-base alloy castings to: (*1*) establish the relationship between standard test bar properties and the properties of castings as influenced by consideration of mass, section, and cooling rate, and (*2*) evaluation of the basic engineering characteristics of the various alloys under the jurisdiction of the subcommittee.

The subcommittee is reactivating the task group to review Specifications B 61 and B 62 and is studying the preparation of a document similar to the Code of Procedure in Inspection of Copper-Base Alloy Sand Castings adopted by the British Standards Institution in 1947.

Subcommittee G-1 on Methods of Test (G. R. Gohn, chairman, J. P. Guerard, secretary) is continuing its studies on the effect of speed of testing on tensile properties, the relation of Rockwell hardness to thickness of specimen and the development of methods of tension testing for thin sheet metals. It is also reviewing the possibility of combining the Tentative Methods of Tension Testing of Copper and Copper Alloy Rods, Bars, and Shapes (B 220 - 48 T) with the Standard Methods of Tension Testing of Metallic Materials (E 8 - 46). The latter suggestion has been made by Committee E-1 on Methods of Testing.

Subcommittee G-2 on Tolerances (J. E. McGraw, chairman) recommended the revisions of dimensional tolerances in plate, sheet and strip; rod and bar; and wire specifications to correspond with current CABRA standards. The revision of weight tolerances in Specifications B 88 was recommended, and the subcommittee also prepared straightness tolerances for shafting and a method for measuring such straightness in Specifications B 21, B 138, B 139, and B 150. The subcommittee also prepared straightness tolerances for bus bars.

The subcommittee is studying the preparation of closer straightness tolerances for slit materials, dimensional tolerances for square, rectangular, and miscellaneous round tubes in Specifications B 188. Also it is preparing revised tolerances for Specifications B 111.

Subcommittee G-3 on Editorial and Publications (W. F. Roeser, chairman) recommended the revision of chemical limits in applicable specifications for wrought products to eliminate slight discrepancies in composition and in the number of significant figures. It also recommended the elimination of such terms as "grade," "type," and "class" in designating alloys, and that the expression "alloy" or "alloy number" be substituted.

The subcommittee is continuing the study of nomenclature and classification of wrought alloys under the jurisdiction of the committee.

This report has been submitted to letter ballot of the committee, which consists of 120 voting members; 100 members returned their ballots, of whom 94 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

G. H. HARNDEN,
Chairman.

V. P. WEAVER,
Secretary.

APPENDIX

RECOMMENDATIONS AFFECTING STANDARDS FOR COPPER AND COPPER ALLOYS

In this Appendix are given the recommendations affecting certain standards covering copper and copper alloys which are referred to earlier in this report. The standards appear in their present form in the 1946 Book of A.S.T.M. Standards, Part I-B or in the 1947 and 1948 Supplements to the Book of A.S.T.M. Standards, Part 1-B.

REVISIONS OF TENTATIVE SPECIFICATIONS

The committee recommends that the following 25 tentative specifications be revised as indicated below and continued as tentative.

Tentative Specifications for Cartridge Brass Sheet, Strip, Plate, Bar, and Disks (B 19 – 47 T):

Section 5.—Revise to read as follows: "Samples for chemical analysis shall be taken in accordance with the Standard Method of Sampling Wrought Non-Ferrous Metals and Alloys for Determination of Chemical Composition (A.S.T.M. Designation: E 55).[1] The lot size, portion size, and selection of pieces shall be as follows:

Lot Size.—40,000 lb. or fraction thereof.

Portion Size.—Pieces from at least ten individual lengths of the finished product. If the lot consists of less than the number of lengths indicated in the porton size, a piece shall be taken from each individual length.

Minimum Weight of Composite Sample.—150 g. divided into three equal parts.

Table I.—Revise certain tensile strength values as follows:

Present Value, psi.	Revised Value, psi.
56 500	57 000
66 500	67 000
82 500	83 000
91 500	92 000
90 500	91 000
99 500	100 000

New Section.—Add a new Section 14 to read as follows renumbering the subsequent sections accordingly.

14. *Significance of Numerical Limits.*—For purposes of determining compliance with the specified limits for requirements of the properties listed in the following table, an observed, or a calculated value, shall be rounded off as indicated in accordance with the rounding-off method of the Tentative Recommended Practices for Designating Significant Places in Specified Limiting Values (A.S.T.M. Designation: E 29):[2]

Property[*]	Rounded-Off Unit for Calculated or Observed Value
Chemical Composition Permanent Set Maximum Compression Hardness Electrical Resistivity Electrical Conductivity	Nearest unit in the last right-hand place of figures
Tensile Strength Yield Strength Deformation Limit	Nearest 1000 psi.
Grain Size:	
Up to 0.055 mm., incl.	Nearest multiple of 0.005 mm.
Over 0.055 to 0.160 mm., incl	Nearest 0.01 mm.
Elongation:	
Below 5 per cent	Nearest multiple of 0.5 per cent
5 per cent and over	Nearest 1 per cent

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[*] Include only those properties which apply to these specifications.

[1] 1946 Book of A.S.T.M. Methods of Chemical Analysis of Metals.

[2] 1948 Supplement to Book of A.S.T.M. Standards, Part I-B.

Table V.—In the first column, lines 12 and 13, revise thickness "0.187" to read "0.188" in.

Table VI.—In the first column, second line revise thickness "0.187" to read "0.188" in. and also in the fifth line revise width "60" to read "120" in. For "Sawed Metal" revise to read as shown in the accompanying Table I.

TABLE I.—WIDTH TOLERANCES FOR SAWED METAL.

Width, in.	Width Tolerances, plus and minus[a], in.			
	For Lengths up to 10 ft., incl.		For Lengths over 10 ft.	
	For Thicknesses up to 1½ inches, incl.	For Thicknesses over 1½ inches	For Thicknesses up to 1½ inches, incl.	For Thicknesses over 1½ inches
Up to 12, incl.	1/32	1/16	3/64	1/16
Over 12 to 120, incl.	1/16	1/16	1/16	1/16

[a] If tolerances are desired all plus or all minus, double the values given.

TABLE II.—LENGTH TOLERANCES FOR SPECIFIC AND STOCK LENGTHS WITH AND WITHOUT ENDS.

NOTE.—The following length tolerances are all plus; if all minus tolerances are desired use the same values; if tolerances are desired plus and minus, halve the values given.

Length, ft.	Length Tolerances, in. (Applicable only to Full Length Pieces)
Specific lengths:	
10 and under	1/4
Over 10 to 20, incl.	1/2
Specific lengths with ends	1
Stock lengths with or without ends	1[a]

[a] As stock lengths are cut and placed in stock in advance of orders, departure from this tolerance is not practicable.

Section 14 (d).—Revise Items (*1*) and (*2*) to read as follows:

(1) *Specific and Stock Lengths With and Without Ends.*—When specific lengths are required they shall be specified in the order. Unilateral plus tolerances from the nominal length specified shall be permitted as prescribed in Table VIII (accompanying Table II).

(2) *Specific and Stock Lengths With Ends.*—When specific or stock lengths are ordered with ends, short lengths shall be accepted in accordance with the requirements prescribed in Table IX (accompanying Table III).

New Table.—Add a new Table VIII to read as shown in the accompanying Table II, renumbering subsequent tables accordingly.

Table VIII.—Renumber as Table IX and revise to read as shown in the accompanying Table III.

Tentative Specifications for Naval Brass Rods, Bars, and Shapes (B 21 - 48 T):

Section 1.—Revise the term "grade" to read "alloy" and make corresponding changes in Section 2, Item (*1*), Section 7, and Tables I and II.

Section 4.—In the first line revise the words "naval brass" to read "material".

Table I.—Delete Note 2.

Section 5.—Revise to read as follows: "Samples for chemical analysis shall be taken in accordance with the Standard Method of Sampling Wrought Non-Ferrous Metals and Alloys for Determination of Chemical Composition (A.S.T.M. Designation: E 55).[1] The lot size, portion size, and selection of pieces shall be as follows:

Lot Size.—5000 lb. or fraction thereof.

Portion Size.—Pieces from four individual lengths of finished product. If the lot consists of less than the number of lengths indicated in the portion size, a piece shall be taken from each individual length.

Minimum Weight of Composite Sample.—150 g. divided into three equal parts."

Table II.—Delete the last column and revise the requirements for minimum elongation in per cent as indicated below:

TABLE III.—SCHEDULE OF LENGTHS (SPECIFIC AND STOCK) WITH ENDS.

Nominal Length, ft.	0.050 in. and under in thickness		Over 0.050 to 0.125 in., incl., in thickness		Over 0.125 to 0.250 in., incl., in thickness	
	Minimum Length of Shortest Piece, ft.	Maximum Permissible Weight of Ends, Per Cent of Lot Weight	Minimum Length of Shortest Piece, ft.	Maximum Permissible Weight of Ends, Per Cent of Lot Weight	Minimum Length of Shortest Piece, ft.	Maximum Permissible Weight of Ends, Per Cent of Lot Weight
6 to 8, excl.	4	20	4	25	3	30
8 to 10, excl.	6	25	5	30	4	35
10 to 14, excl.	7	30	6	35	5	40

Grade A		Grade B		Grade C	
Present, in 2 in.	Revised Elongation, min., per cent[a]	Present, in 2 in.	Revised Elongation, min., per cent[a]	Present, in 2 in.	Revised Elongation, min., per cent[a]
35	30	35	25	20	20
40	30	40	25	25	20
40	30	40	25	30	20
25	22	25	18	12	12
30	25	25	20	15	15
30	25	25	20	20	20
30	27	30	20	25	20
30	30	30	25	25	20
17	13	14	11	10	10
25	18	18	15	15	13
30	27	25	20	20	20
30	30	25	25	20	20
30	30	30	25	20	20

[a] Elongation shall be determined on a gage length of 4 × diameter or thickness of specimen except that in any case a minimum gage length of 1 in. shall be used.

Section 7.—Delete and renumber subsequent sections accordingly.

Section 9.—Renumber as section 8 and delete Paragraph (*b*).

Section 10.—Renumber as Section 9 and in Paragraph (*b*) delete the reference to bend test specimen.

New Section.—Add a new Section 11 to read as indicated above for new Section 14 in Specifications B 19.

Table IV.—Revise to read as shown in the accompanying Table V.

Table V.—Revise to read as shown in the accompanying Table VI.

Table VI.—Revise to read as shown in the accompanying Table VII.

Section 12 (*b*).—Add a new Item (*3*) to read "(*3*) *Specific Lengths With Ends.*—The tolerance for specific lengths with ends is plus 1 in.

Section 14.—Add a new Paragraph (*c*) to read as follows, relettering the present Paragraph (*c*) as (*d*) and deleting the reference to shafting:

(*c*) The straightness tolerances for shafting are as follows:

Length of Shaft, ft.	Maximum Permissible Departure from Straightness of Either Center or End Portions, in	Minimum Diameter Applicable for Length Indicated, in.
Up to 6, incl.	0.005	½
7	0.007	½
8	0.009	½
9	0.012	½
10	0.014	½
11	0.017	½
12	0.020	½
14	0.028	⅝
16	0.036	¾
18	0.045	1
20	0.055	1¼
22	0.068	1½
24	0.078	1¾
26	0.094	2

NOTE.—To determine compliance with this paragraph, shafting shall, in case of disagreement, be checked by the following method: Place the shaft upon two freely rotating supports, one-fourth of the shaft length extending beyond each support. Measure the departure from straightness at each end and at the center by means of a dial gage mounted on a suitable movable block and set successively at the three points to be measured while rotating the shaft slowly and carefully to avoid vibration. The total range of the dial reading at a given point divided by two gives the departure from straightness at that point.

Section 15.—Revise Paragraph (*b*) to read "... with a maximum permissible radius of $\frac{1}{32}$ in. for bars over $\frac{3}{16}$ to 1 in., inclusive, in thickness, and $\frac{1}{16}$ in. for bars over 1 in. in thickness."

Revise the first sentence of Paragraph (*c*) to read "... with a radius of $\frac{1}{16}$ in. for bars over $\frac{3}{16}$ to 1 in., inclusive, in thickness, and $\frac{1}{8}$ in. for bars over 1 in. in thickness."

Tentative Specifications for Brass Plate, Sheet and Strip (B 36 - 48 T):

Section 5.—Revise to read as indicated above for Section 5 in Specifications B 21.

Table I.—Revise certain tensile strength values as follows:

Alloy No.	Present Value, psi.	Revised Value, psi.
1	59 500	60 000
	67 500	68 000
3	71 500	72 000
	79 500	80 000
4	54 500	55 000
	64 500	65 000
6	56 500	57 000
	66 500	67 000
	82 500	83 000
	91 500	92 000
	90 500	91 000
	99 500	100 000
8	88 500	89 000
	89 500	90 000
	98 500	99 000

New Section.—Add a new Section 14 to read as indicated above for new Section 14 in Specifications B 19, renumbering the subsequent sections accordingly.

TABLE IV.—TENSILE REQUIREMENTS FOR ALLOY D.

Temper	Thickness, in.	Width, in.	Tensile Strength, min., psi.	Yield Strength, min., psi.	Elongation in 2 in., min per cent
Soft	Under ⅛	All widths	75 000	42 000	30
	Over ⅛ to 5/16	All widths	72 000	38 000	32
	Over 5/16 to ½	All widths	72 000	32 000	35
	Over ½	All widths	70 000	30 000	40
Hard	Under ⅛	All widths	85 000	55 000	30
	Over ⅛ to 5/16	All widths	80 000	50 000	30
	Over 5/16 to ½	All widths	75 000	45 000	35
	Over ½	All widths	70 000	40 000	40

Table IV.—In the first column, lines 12 and 13, revise the thickness "0.187" to read "0.188" in.

Table V.—In the heading for the third column revise the thickness "0.187" to read "0.188" in. Delete the portion headed "Rolled Edge Metal (Not Previously Slit)." Under "Square Sheared Metal," first column, revise width "60" to read "120" in. For "Sawed Metal" revise to read as shown in the accompanying Table I.

Table VI.—Revise to read as shown in the accompanying Table II.

Section 14 (*c*).—Revise title of Item (*1*) to read "Specific and Stock Lengths with Ends."

Table VII.—Revise to read as shown in the accompanying Table III.

Table VIII.—Delete the portion headed "Rolled Edge Metal (Not Previously Slit)."

Tentative Specifications for Seamless Copper Tubes (B 75 - 48 T):

Section 1.—Delete type E and make a corresponding deletion in Section 4. Revise type designations A, B, C, and D to read DLP, DHP, DPA and OF respectively, and make corresponding revisions in Sections 4, 10, 11, and 12. Add a note explaining the redesignation of these alloys.

Section 5.—Revise to read as indicated above for Section 5 in Specifications B 21 except that the portion size shall read

TABLE V.—THICKNESS TOLERANCES FOR RECTANGULAR AND SQUARE BARS.
Tolerances are plus and minus; if tolerances all plus or all minus are desired, double the values given.

Thickness, in.	Width, in.					
	½ and under	Over ½ to 1¼, incl.	Over 1¼ to 2.00, incl.	Over 2.00 to 4.00, incl.	Over 4.00 to 8.00, incl.	Over 8.00 to 12.00, incl.
Over 0.188 to 0.500 incl.	0.0035	0.004	0.0045	0.0045	0.006	0.008
Over 0.500 to 1.00 incl.	...	0.0045	0.005	0.005	0.007	0.009
Over 1.00 to 2.00 incl.	...	0.005	0.005	0.006	0.008	...
Over 2.00 to 4.00 incl.	...	...	...	0.30 per cent[a]	...	...

[a] Expressed to the nearest 0.001 in.

TABLE VI.—WIDTH TOLERANCES FOR RECTANGULAR BARS.

Width, in.	Tolerances, plus and minus,[a] in.
0.050 and under	0.0013
Over 0.050 to 0.090, incl.	0.0015
Over 0.090 to 0.130, incl.	0.002
Over 0.130 to 0.188, incl.	0.003
Over 0.188 to 0.500, incl.	0.0035
Over 0.500 to 1.25, incl.	0.005
Over 1.25 to 2.00, incl.	0.008
Over 2.00 to 4.00, incl.	0.012
Over 4.00 to 12.00, incl.	0.30 per cent[b]

[a] When tolerances are specified as all plus or all minus, double the values given.
[b] Expressed to the nearest 0.001 in.

"pieces from 0.5 per cent of the number of individual lengths of finished product".

New Section.—Add a new Section 15 to read as indicated above for new Section 14 in Specifications B 19, renumbering subsequent sections accordingly.

New Appendix.—Add an appendix to read as follows: "It is recommended that wherever possible, material purchased to these specifications be ordered to the diameters and wall thicknesses indicated in Table V (accompanying Table VIII).

Tentative Specifications for Leaded Brass Plate, Sheet and Strip (B 121 – 47 T):

Section 4.—For alloy No. 1 revise the present copper content range of "89.00 to 91.00" to read "89.0 to 91.0" per cent.

Section 5.—Revise to read as indicated above for Section 5 in Specifications B 21.

Table I.—Revise certain tensile strength values for alloy Nos. 2, 3, 4 and 6 as follows:

Present Value, psi.	Revised Value, psi.
88 500	89 000
89 500	90 000
98 500	99 000

New Section.—Add a new Section 14 to read as indicated above for new Section 14 in Specifications B 19, renumbering subsequent sections accordingly.

Tables IV and V.—Revise as indi-

TABLE VII.—SCHEDULE OF LENGTHS (SPECIFIC AND STOCK) WITH ENDS.

Diameter or Distance Between Parallel Surfaces for Round, Hexagonal, Octagonal Rods and Square Bars, in.	Rectangular Bars, Area[a], sq. in.	Nominal Length, ft.	Shortest Permissible Length,[b] Per Cent of Nominal Length	Maximum Permissible Weight of Ends, Per Cent of Lot Weight
½ and under	0.250 and under	6 to 14, incl.	75	20
Over ½ to 1, incl.	Over 0.250 to 1, incl.	6 to 14, incl.	70	30
Over 1 to 1½, incl.	Over 1 to 2.25, incl.	6 to 12, incl.	60	40
Over 1½ to 2, incl.	Over 2.25 to 4, incl.	6 to 12, incl.	50	45
Over 2 to 3, incl.	Over 4 to 9, incl.	6 to 10, incl.	40	50

[a] Width times thickness, disregarding any rounded corners or edges.
[b] Expressed to the nearest ½ ft.

cated above for Tables IV and V in Specifications B 36.

Tables VI and VII.—Revise to read as shown in the accompanying Tables II and III.

Table VIII.—Delete the portion headed "Rolled Edge Metal (Not Previously Slit)."

Section 5.—Revise to read as indicated above for Section 5 in Specifications B 21.

Table II.—Delete Footnote *a*.

New Section.—Add a new Section 14 to read as indicated above for new Section 14 in Specifications B 19, renumbering subsequent sections accordingly.

TABLE VIII.—PREFERRED SIZES OF ROUND SEAMLESS COPPER TUBE.[a, b]
[× indicates the preferred sizes]

Outside Diameter, in.	Wall Thickness, in.																		
	0.010	0.013	0.016	0.020	0.025	0.032	0.040	0.049	0.065	0.083	0.100	1/8	5/32	3/16	1/4	5/16	3/8	1/2	5/8
1/8	×	×	×	×	×	×	×	...	...	...	...	...	...	...	...	...	...	...	...
3/16	×	×	×	×	×	×	×	×	...	...	...	...	...	...	...	...	...	...	...
1/4	...	...	×	×	×	×	×	×	×	×	...	...	...	...	...	...	...	...	...
5/16	...	...	×	×	×	×	×	×	×	×	×	...	...	...	...	...	...	...	...
3/8	...	...	×	×	×	×	×	×	×	×	×	×	...	...	...	...	...	...	...
1/2	...	...	×	×	×	×	×	×	×	×	×	×	×	...	...	...	...	...	...
5/8	...	...	×	×	×	×	×	×	×	×	×	×	×	...	...	...	...	...	...
3/4	...	...	×	×	×	×	×	×	×	×	×	×	×	×	...	...	...	...	...
7/8	...	...	×	×	×	×	×	×	×	×	×	×	×	×	...	...	...	...	...
1	...	...	...	×	×	×	×	×	×	×	×	×	×	×	×	...	...	...	...
1 1/4	...	...	...	×	×	×	×	×	×	×	×	×	×	×	×	×	...	...	...
1 1/2	...	...	...	×	×	×	×	×	×	×	×	×	×	×	×	×	×	...	...
1 3/4	...	...	...	×	×	×	×	×	×	×	×	×	×	×	×	×	×	...	...
2	...	...	...	...	×	×	×	×	×	×	×	×	×	×	×	×	×	×	...
2 1/4	...	...	...	...	×	×	×	×	×	×	×	×	×	×	×	×	×	×	...
2 1/2	...	...	...	...	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
2 3/4	...	...	...	...	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
3	...	...	...	...	...	×	×	×	×	×	×	×	×	×	×	×	×	×	×
3 1/2	...	...	...	...	...	×	×	×	×	×	×	×	×	×	×	×	×	×	×
4	...	...	...	...	...	...	×	×	×	×	×	×	×	×	×	×	×	×	×
4 1/2	...	...	...	...	...	...	×	×	×	×	×	×	×	×	×	×	×	×	×
5	...	...	...	...	...	...	...	×	×	×	×	×	×	×	×	×	×	×	×
5 1/2	...	...	...	...	...	...	...	×	×	×	×	×	×	×	×	×	×	×	×
6	...	...	...	...	...	...	...	...	×	×	×	×	×	×	×	×	×	×	×
7	...	...	...	...	...	...	...	...	×	×	×	×	×	×	×	×	×	×	×
8	...	...	...	...	...	...	...	...	...	×	×	×	×	×	×	×	×	×	×
9	...	...	...	...	...	...	...	...	...	×	×	×	×	×	×	×	×	×	×
10	...	...	...	...	...	...	...	...	...	...	×	×	×	×	×	×	×	×	×
11	...	...	...	...	...	...	...	...	...	...	×	×	×	×	×	×	×	×	×
12	...	...	...	...	...	...	...	...	...	...	...	×	×	×	×	×	×	×	...

[a] In conformance with the Simplified Practice Recommendations R 235-48 for Copper and Copper-Alloy Round Seamless Tube issued by the U. S Department of Commerce.

[b] This tube is not necessarily available in all alloys in the full range of sizes shown.

Tentative Specifications for Copper-Nickel-Zinc and Copper-Nickel Alloy Plate, Sheet and Strip (B 122 - 48 T):

Table I.—For alloy Nos. 5, 6, and 7, revise the iron, tin, manganese and zinc requirements by deleting the zeros in the last right-hand place of the figures, and for these same alloys, substitute "Copper plus sum of named elements, 99.5 min., per cent," for "Copper remainder." Delete Footnote *b*.

Tables IV and V.—Revise as indicated above for Tables IV and V in Specifications B 36.

Table VI.—Revise to read as shown in the accompanying Table II.

New Table.—Add a new Table VII to read as shown in the accompanying Table III, renumbering subsequent tables accordingly.

Tentative Specifications for Cartridge Brass Cartridge Case Cups (B 129-47 T):

Section 5.—Revise to read as indicated above for Section 5 in Specifications B 19 except that for portion size the first statement shall be "Pieces from at least 20 cups in the lot for type I, or two cups for type II".

New Section.—Add a new Section 8 to read as indicated above for new Section 14 in Specifications B 19, renumbering subsequent sections accordingly.

Tentative Specifications for Gilding Metal Strip (B 130 - 47 T):

Section 5.—Revise to read as indicated above for Section 5 in Specifications B 19.

New Section.—Add a new Section 14 to read as indicated above for new Section 14 in Specifications B 19, renumbering subsequent sections accordingly.

Table IV.—In the last line revise thickness "0.187" to read "0.188" in.

Table V.—In the heading for the third column revise thickness "0.187" to read "0.188" in. Delete the portion on "Rolled Edge Metal (Not Previously Slit)".

Tables VI and VII.—Revise to read as shown in the accompanying Tables II and III.

Table VIII.—Delete the portion on "Rolled Edge Metal (Not Previously Slit)."

Tentative Specifications for Gilding Metal Bullet Jacket Cups (B 131 - 47 T):

Section 5.—Revise to read as indicated above for Section 5 in Specifications B 19, except that for portion size the statement shall be "Pieces from at least 20 cups in the lot."

New Section.—Add a new Section 9 to read as indicated above for new Section 14 in Specifications B 19, renumbering subsequent sections accordingly.

Tentative Specifications for Copper Rods, Bars, and Shapes (B 133 - 48 T):

Section 6.—Revise to read as indicated above for Section 5 in Specifications B 21 except that the lot size shall be 10,000 lb.

Table I.—Revise the requirements for minimum elongation in per cent as follows:

Present, in 2 in.	Revised Elongation min., per cent.[a]
25	25
25	20
10	8
12	10
15	12
20	15
10	10
12	12
15	15
20	15

---

[a] Elongation shall be determined on a gage length of 4 × diameter or thickness of specimen except that in any case a minimum gage length of 1 in. shall be used.

Section 10.—Change the reference to Section 6 (*c*) to refer to Section 14 (*a*).

Section 11.—Change the reference to Section 6 (*d*) to refer to Section 14 (*b*).

Section 14.—Incorporate the present Paragraphs (*c*) and (*d*) of Section 6 as new Paragraphs (*a*) and (*b*) of Section 14. Revise the present reference to Paragraph (*a*) in Section 6 (*c*) and Section 6 (*d*) to read Section 6. Reletter the present Paragraphs (*a*) and (*b*) of Section 14 respectively as (*c*) and (*d*), revising the reference to Section 6 (*a*) in Paragraph (*a*) to refer to Section 6.

New Section.—Add a new Section 16 to read as indicated above for new Section 14 in Specifications B 19, renumbering subsequent sections accordingly.

Section 17 (c).—Add a new Item (*3*) to read as indicated above for Section 12 (*b*) in Specifications B 21.

Section 19.—Renumber as Section 20 and revise Paragraphs (*b*) and (*c*) as indicated above for Section 15 in Specifications B21.

Tentative Specifications for Miscellaneous Brass Tubes (B 135 – 47 T):

Title.—Revise by substituting the word "seamless" for "miscellaneous."

Section 1.—Add the word "seamless" before "commercial."

Section 4.—For alloy No. 1 change the copper content range from the present "83.0 to 86.0" to read "84.0 to 86.0" per cent.

For alloy No. 2 change the maximum permissible lead content from the present "0.075" to read "0.07" per cent, and change the maximum permissible iron content from the present "0.06" to read "0.05" per cent.

For alloy No. 3 change the lead content range from the present "0.30 to 0.80" to read "0.3 to 0.8" per cent.

For alloy No. 4 change the lead content range from the present "1.25 to 2.00" to read "1.3 to 2.0" per cent.

For alloy No. 5 change the maximum permissible lead content from the present "0.80" to read "0.8" per cent.

Section 5.—Revise to read as indicated above for Section 5 in Specifications B 21 except that the portion size shall read "Pieces from 0.5 per cent of the number of individual lengths of the finished product."

New Section.—Add a new Section 13 as indicated above for new Section 14 in Specifications B 19, renumbering subsequent sections accordingly.

New Appendix.—Add an appendix as indicated above for Specifications B 75, excepting the title of the table will refer to brass tubing in place of copper tubing.

Tentative Specifications for Phosphor Bronze Rods, Bars, and Shapes (B 139 – 48 T):

Section 1.—Revise the term "grade" to read "alloy" through the section and make corresponding revisions in Section 2, Item (*1*), and Table I and II.

Table I.—Delete the zeros in the last right hand place of figures for the tin content in all grades, the lead and zinc limits for grade B2, and for copper plus other elements specified for all grades. Delete "copper remainder."

Revise the lead content range for grade B1 from the present "0.80 to 1.25" to read "0.8 to 1.2" per cent.

For grade D revise the phosphorus content range from the present "0.03 to 0.25" to read "0.03 to 0.35" per cent. For copper plus other elements specified revise the present "99.60" to read "99.5" per cent.

Revise Footnote *a* to read "... iron content of 1.2 per cent may be permitted providing that the copper plus tin plus lead plus phosphorus plus iron plus manganese content is not less than 99.5 per cent."

Section 5.—Revise to read as indicated above for Section 5 in Specifications B 21 except that minimum sample weight shall be 225 g.

Table II.—Revise the requirements for minimum elongation in per cent as follows:

Grade	Present, in 2 in.	Revised Elongation min., per cent[a]
A	12	13
	15	15
	20	18
	10	10
	15	15
	3.5	3.5
	5.0	5.0
	9.0	9.0
B1, B2	12	10
	15	12
	20	15
	10	10
	15	15
C	12	12
	15	15
	20	20
	10	10
	15	15
D	12	10
	15	12
	20	15
	10	10
	15	15

---

[a] Elongation shall be determined on a gage length of 4 × diameter or thickness of specimen except that in any case a minimum gage length of 1 in. shall be used.

TABLE IX.—THICKNESS TOLERANCES FOR RECTANGULAR AND SQUARE BARS.
Tolerances are plus and minus; if tolerances all plus or all minus are desired, double the values given.

Thickness, in.	Width, in.					
	½ and under	Over ½ to 1¼ incl.	Over 1¼ to 2.00, incl.	Over 2.00 to 4.00, incl.	Over 4.00 to 8.00, incl.	Over 8.00 to 12.00, incl.
Over 0.188 to 0.500, incl.	0.005	0.005	0.006	0.007	0.009	0.012
Over 0.500 to 1.00, incl.	...	0.006	0.007	0.008	0.010	0.013
Over 1.00 to 2.00, incl.	...	0.006	0.007	0.009	0.011	...
Over 2.00 to 4.00, incl.	...	...	...	0.50 per cent[a]	...	...

[a] Expressed to the nearest 0.001 in.

Section 7.—Delete and renumber subsequent sections accordingly.

Section 8.—Renumber as Section 7 and delete Paragraph (*b*).

Section 9.—Renumber as Section 8 and in Paragraph (*b*) delete the reference to bend test specimen.

New Section.—Add a new Section 10 to read as indicated above for new Section 14 in Specifications B 19.

Table IV.—Revise to read as shown in the accompanying Table IX.

Table V.—Revise to read as shown in the accompanying Table X.

TABLE X.—WIDTH TOLERANCES FOR RECTANGULAR BARS.

Width, in.	Tolerances, plus and minus,[a] in.
0.050 and under	0.0015
Over 0.050 to 0.090, incl.	0.002
Over 0.090 to 0.130, incl.	0.003
Over 0.130 to 0.188, incl.	0.004
Over 0.188 to 0.500, incl.	0.005
Over 0.500 to 1.25, incl.	0.007
Over 1.25 to 2.00, incl.	0.010
Over 2.00 to 4.00, incl.	0.015
Over 4.00 to 12.00, incl.	0.50 per cent[b]

[a] When tolerances are specified as all plus or all minus, double the values given.

[b] Expressed to the nearest 0.001 in.

Table VI.—Revise to read as shown in the accompanying Table XI.

Section 11 (c).—Add a new Item (*3*) to read as indicated above for Section 12 (*b*) in Specifications B 21.

Section 13.—Revise as indicated above for Section 14 in Specifications B 21.

Section 14.—Revise Paragraphs (*b*) and (*c*) as indicated above for Sections 15 (*b*) and (*c*) in Specifications B 21.

Tentative Specifications for Aluminum Bronze Rods, Bars, and Shapes (B 150 - 48 T):

Section 4.—Revise alloy designations types I and II to read respectively "alloy Nos. 1 and 2" and make corresponding revisions in Section 6, Table I.

For types I and II delete the final zero in the last right hand place of figures in the requirements for copper, aluminum, iron, nickel, manganese, and for tin and zinc in type I.

For type I revise the maximum silicon

TABLE XI.—SCHEDULE OF LENGTHS (SPECIFIC AND STOCK) WITH ENDS.

Diameter or Distance Between Parallel Surfaces for Round, Hexagonal, Octagonal Rods and Square Bars, in.	Rectangular Bars, Area[a], sq. in.	Nominal Length, ft.	Shortest Permissible Length,[b] per cent of Nominal Length	Maximum Permissible Weight of Ends, per cent of Lot Weight
½ and under	0.250 and under	6 to 12, incl.	65	30
Over ½ to 1, incl.	Over 0.250 to 1, incl.	6 to 12, incl.	60	40
Over 1 to 1½, incl.	Over 1 to 2.25, incl.	6 to 10, incl.	50	50
Over 1½ to 2, incl.	Over 2.25 to 4, incl.	6 to 10, incl.	40	60

[a] Width times thickness, disregarding any rounded corners or edges.

[b] Expressed to the nearest ½ ft.

limit from the present "2.25" to read "2.2" per cent and tellurium from the present "0.65" to read "0.6" per cent. Revise the last item in the tabulation to read "Sum of named elements, min., per cent . . . 99.5" for types I and II.

Section 5.—Revise to read as indicated above for Section 5 in Specifications B 21 except that minimum weight 150 g. shall be 225 g.

Table I.—Revise the requirements for minimum elongation in per cent as follows:

Type	Present, in 2 in.	Revised Elongation, min., per cent[a]
I	15	9
	15	10
	20	12
	15	12
II	10	5
	12	6
	15	10

---

[a] Elongation shall be determined on a gage length of 4 × diameter or thickness of specimen except that in any case a minimum gage length of 1 in. shall be used.

Section 7.—Delete and renumber subsequent sections accordingly.

Section 9.—Renumber as Section 8 and delete Paragraph (*b*).

Section 10.—Renumber as Section 9 and in Paragraph (*b*) delete the reference to bend test specimen.

New Section.—Add a new Section 11 to read as indicated above for new Section 14 in Specifications B 19.

Section 12 (*c*).—Add a new Item (*3*) to read as indicated above in Section 12 (*b*) of Specifications B 21.

Tables III and IV.—Revise to read as shown in the accompanying Tables IX and X.

Table VII.—Revise to read as shown in the accompanying Table XI.

Section 14.—Revise as indicated above for Section 14 in Specifications B 21.

Section 15.—Revise Paragraphs (*b*) and (*c*) as indicated above for Section 15 (*b*) and (*c*) in Specifications B 21.

Tentative Specifications for Copper-Nickel-Zinc Alloy Rods and Bars (B 151 - 48 T):

Table I.—Delete Footnote *a*.

Section 6.—Revise to read as indicated above for Section 5 in Specifications B 21.

Table II.—Delete Footnote *a*.

Table III.—Delete Footnote *a*.

New Section.—Add a new Section 12 to read as indicated above for new Section 14 in Specifications B 19, renumbering subsequent sections accordingly.

Tables V, VI and VII.—Revise to read as shown in the accompanying Tables, IX, X and XI.

Section 12.—Renumber as Section 13 and revise Paragraph (*b*) as indicated above for Section 12 (*b*) in Specifications B 21.

Section 14.—Renumber as Section 15 and revise Paragraphs (*b*) and (*c*) as indicated above for Section 15 (*b*) and (*c*) in Specifications B 21.

Tentative Specifications for Copper Sheet, Strip, and Plate (B 152 - 48 T):

Table I.—For types DHP and DPS, revise the maximum phosphorus content from the present "0.04" to read "0.040" per cent.

Section 5.—Revise to read as indicated above for Section 5 in Specifications B 21 except that the lot size shall be 10,000 lb.

Section 14.—Revise the present conductivity "100" to read "100.00" per cent.

New Section.—Add a new Section 17 to read as indicated above for new Section 14 in Specifications B 19, renumbering subsequent sections accordingly.

Table IV.—In the first column, lines 12 and 13, revise present thickness "0.187" to read "0.188" in.

Table V.—In the heading for the third column revise thickness "0.187" to read "0.188" in. Under "Square Sheared Metal," first column, revise present width "60" to read "120" in.

Revise the portion on "Sawed Metal" to read as shown in the accompanying Table I.

Table VI.—Revise to read as shown in the accompanying Table II.

New Table.—Add a new Table VII to read as shown in the accompanying Table III, renumbering subsequent tables accordingly.

Tentative Specifications for Phosphor Bronze Wire (B 159 - 47 T):

Section 1.—Revise the term "grade" to read "alloy" throughout the section and make corresponding revisions in Section 2, Item (*1*), Tables I, II, and III, Section 8, and in the Explanatory Note.

Table I.—For all grades delete the final zero in the last right-hand place of figures in the limits for tin and copper plus tin plus phosphorus. Delete "copper remainder." For grade D revise the phosphorus content range from the present "0.03 to 0.25" to read "0.03 to 0.35" per cent and for copper plus other elements specified revise the present "99.60" to read "99.5" per cent. Delete Footnote *a*.

Section 5.—Revise to read as indicated above for Section 5 in Specifications B 21, except that for portion size "length" shall read "coil", and minimum sample weight shall be 225 g.

Tables II and III.—Delete Footnote *b*.

New Section.—Add a new Section 10 to read as indicated above for new Section 14 in Specifications B 19, renumbering subsequent sections accordingly.

Tentative Specifications for Aluminum Bronze, Plate, Sheet and Strip (B 169 - 47 T):

Section 1 (a).—Revise the second sentence to read "Three alloys designated A, C, and D are specified as shown in Table I."

Section 2.—Revise Item (*1*) to read: "(*1*) Alloy designation (Table I)."

Section 4.—Revise Table I to read:

	Alloy A	Alloy C	Alloy D
Copper, per cent	92.0 to 96.0	90.0 to 93.0	88.0 to 92.5
Aluminum, per cent	4.0 to 7.0	7.0 to 9.0	6.0 to 8.0
Iron, per cent	0.50 max.	0.50 max.	1.5 to 3.5
Copper plus aluminum plus iron, min., per cent	99.5	99.5	99.5

Section 5.—Revise to read as indicated above for Section 5 in Specifications B 21.

Table II.—Add requirements for alloy D as shown in the accompanying Table IV.

New Section.—Add a new Section 10 to read as indicated above for new Section 14 in Specifications B 19, renumbering subsequent sections accordingly.

Tables III and IV.—Revise as indicated above for Tables IV and V in Specifications B 152.

Tables V and VI.—Revise to read as shown in the accompanying Tables II and III.

Tentative Specifications for Copper Bus Bars, Rods, and Shapes (B 187 - 48 T):

Section 4 (b).—Revise to read "The copper will normally be of the ETP, OF, OFS, STP or DLP types of the Tentative Classification of Coppers (A.S.T.M. Designation: B 224),[2] but may be of such other types as may be agreed upon between the purchaser and the manufacturer.

Table I.—Revise the requirements for minimum elongation in per cent as follows:

Present, in 2 in.	Revised Elongation, min., per cent[a]
25	25
10	12
20	15
20	15
10	10
20	15
20	15

---

[a] Elongation shall be determined on a gage length of 4 × diameter or thickness of specimen except that in any case a minimum gage length of 1 in. shall be used.

New Section.—Add a new Section 11 to read as indicated above for new

Section 14 in Specifications B 19, renumbering subsequent sections accordingly.

Table III.—Revise to read as shown in the accompanying Table XII.

Tables IV and VI.—Revise to read as shown in the accompanying Tables VI and VII.

TABLE XII.—THICKNESS TOLERANCES FOR RECTANGULAR AND SQUARE BARS.
Tolerances are plus and minus; if tolerances all plus or all minus are desired, double the values given.

Thickness, in.	Width, in.					
	½ and under	Over ½ to 1¼, incl.	Over 1¼ to 2.00, incl.	Over 2.00 to 4.00, incl.	Over 4.00 to 8.00, incl.	Over 8.00 to 12.00, incl.
0.013 and under	0.001	0.001	...	...	...	...
Over 0.013 to 0.050, incl.	0.0013	0.0013	0.0015	...	...	...
Over 0.050 to 0.090, incl.	0.0015	0.0015	0.002	0.0025	...	...
Over 0.090 to 0.130, incl.	0.002	0.002	0.0025	0.003	0.0035	...
Over 0.130 to 0.188, incl.	0.0025	0.0025	0.003	0.0035	0.004	0.005
Over 0.188 to 0.500, incl.	0.003	0.003	0.0035	0.004	0.0045	0.0055
Over 0.500 to 1.00, incl.	...	0.004	0.004	0.0045	0.005	0.006
Over 1.00 to 2.00 incl.	...	0.0045	0.0045	0.005	0.006	...
Over 2.00 to 4.00, incl.	...	...	...	0.30 per cent[a]	...	...

[a] Expressed to the nearest 0.001 in.

Table VII.—Revise to read as shown in the accompanying Table XIII.

Section 13.—Renumber as Section 14 and revise Paragraphs (*b*) and (*c*) as indicated above for Section 15 (*b*) and (*c*) in Specifications B 21.

Tentative Specifications for Copper Bus Pipes and Tubes (B 188 - 47 T):

Title.—Add the word "seamless" before "copper."

Section 1.—Add the word "seamless" before "copper". Add "Copper will normally be of the types OF, OFS, STP, ETP or DLP of the Tentative Classification of Coppers (A.S.T.M. Designation: B 224).[2]

New Section.—Add a new Section 11 to read as indicated above for new Section 14 in Specifications B 19, renumbering subsequent sections accordingly.

Tentative Specifications for Beryllium-Copper Alloy Plate, Sheet and Strip (B 194 - 47 T):

Section 4.—Delete Footnote *a*.

Section 5.—Revise to read as indicated above for Section 5 in Specifications B 21.

New Section.—Add a new Section 12 to read as indicated above for new Section 14 in Specifications B 19, renumbering subsequent sections accordingly.

Tables IV and V.—Revise as indicated above for Tables IV and V in Specifications B 152.

Table VI and VII.—Revise to read as shown in the accompanying Tables II and III.

Tentative Specifications for Beryllium-Copper Alloy Strip, Special Grade (B 195 - 47 T):

Section 4.—Delete Footnote *a*.

Section 5.—Revise to read as indicated above for Section 5 in Specifications B 21.

New Section.—Add a new Section 12 to read as indicated above for new Sec-

TABLE XIII.—STRAIGHTNESS TOLERANCES. APPLICABLE TO ANY LONGITUDINAL SURFACE OR EDGE.

	Maximum Curvature (Depth of Arc), in.	Portion of Total Length in Which Depth of Arc is Measured, in.
Rods	½	120
Shapes	½	72
Bars (except hard-drawn rectangular bars listed in following line)	¼	60
Hard-drawn rectangular bars ⅛ to ⅝ in., incl in thickness, having widths ranging from 2 to 6 in., incl.	⅛	96

tion 14 in Specifications B 19, renumbering subsequent sections accordingly.

Tables VI and VII.—Revise to read as shown in the accompanying Tables II and III.

Tentative Specifications for Beryllium-Copper Alloy Rod and Bar (B 196 - 48 T):

Section 4.—Delete Footnote *a*.

Section 5.—Revise to read as indicated above for Section 5 in Specifications B 21.

Tables II and III.—Revise the requirements for minimum elongation in per cent as follows:

Present, in 2 in.	Revised Elongation, min., per cent[a]
FOR ROD AND BAR AS SUPPLIED COMMERCIALLY	
35	20
10	7
10	8
FOR ROD AND BAR AFTER PRECIPITATION HARDENING	
3	3
2	1
3	2

[a] Elongation shall be determined on a gage length of 4 × diameter or thickness of specimen except that in any case a minimum gage length of 1 in. shall be used.

New Section.—Add a new Section 12 to read as indicated above for new Section 14 in Specifications B 19, renumbering subsequent sections accordingly.

Tables VI and VII.—Revise to read as shown in the accompanying Tables IX and X.

Table VIII.—In the first line, revise thickness "0.187" to read "0.188" in.

Section 12.—Renumber as Section 13 and add a new Paragraph (*g*) to read as indicated above for Section 12 (*b*) in Specifications B 21.

Table X.—Delete and renumber subsequent tables accordingly.

Table XI.—Renumber as Table X and revise to read as shown in the accompanying Table XI.

Section 13.—Renumber as Section 14 and revise Paragraphs (*b*) and (*c*) as indicated above for Sections 15 (*b*) and (*c*) in Specifications B 21.

Tentative Specifications for Beryllium-Copper Alloy Wire (B 197 - 47 T):

Section 4.—Delete Footnote *a*.

Section 5.—Revise to read as indicated above for Section 5 in Specifications B 21 except that in portion size "length" shall read "coil".

Table II.—Delete Footnote *a*.

Table III.—Delete Footnote *a*.

New Section.—Add a new Section 13 to read as indicated above for new Section 14 in Specifications B 19, renumbering subsequent sections accordingly.

Tentative Specifications for Copper-Nickel-Zinc Alloy Wire (B 206 - 47 T):

Section 2.—In Item (*1*) revise "type of alloy" to read "alloy designation".

Table I.—Delete Footnote *a*.

Section 5.—Revise to read as indicated above for Section 5 in Specifications B 21 except that in portion size "length" shall read "coil".

Table II.—Delete Footnote *a*.

New Section.—Add a new Section 13 to read as indicated above for new Section 14 in Specifications B 19, renumbering subsequent sections accordingly.

Tables V and VI.—In the first column, revise thickness "0.187" to read "0.188" in.

Tentative Recommended Practice for Preparing Tension Test Specimens for Copper-Base Alloy Castings (B 208 - 46 T):

The proposed revision of this recommended practice includes more definite sections on scope, test coupons, and methods of casting test specimens with revised drawings which include details for gates and risers, as given in the revised recommended practice appended hereto.[3]

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[3] This revised recommended practice was accepted by the Society and appears in the 1949 Book of A.S.T.M. Standards, Part 2.

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends, for immediate adoption, revisions in 35 specifications as indicated below and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these modifications may be referred to letter ballot of the Society.

Standard Specifications for Copper Plates for Locomotive Fireboxes (B 11 – 47):

Section 1.—Revise grade designations 1, 2, 3 and 4 to read, respectively, Types ETP/FRTP, DHP, ATP and DPA, making a reference to the Tentative Classification of Coppers (A.S.T.M. Designation: B 224) and indicating the present designations as being replaced. Make corresponding revisions in Sections 2, 4, 6, 11 and 13.

Section 4.—For grade 1 revise the minimum copper requirement from the present "99.90" to read "99.88" per cent.

Section 5.—Revise to read as indicated above for Section 5 in Tentative Specifications B 21.

Table I.—In the last column, line 5, add the value "8".

New Section.—Add a new Section 11 to read as indicated above for new Section 14 in Tentative Specifications B 19, renumbering the subsequent sections accordingly.

Standard Specifications for Copper Rods for Locomotive Staybolts (B 12 – 47):

Section 1.—Revise to read "These specifications cover arsenical and nonarsenical copper rods for locomotive staybolts."

Section 2.—In Item (*1*) revise "grade of copper" to read "whether arsenical or nonarsenical."

Section 3.—Add a new Paragraph (*b*) to read as follows relettering the present Paragraph (*b*) as (*c*): " (*b*) The arsenical copper will normally be of types DPA or ATP and the nonarsenical copper of types ETP, FRTP, DHP, DLP or OF of the Tentative Classification of Coppers (A.S.T.M. Designation: B 224).[2]

Section 4.—Revise Paragraph (*a*) to read "(*a*) *Arsenical Copper.*—Arsenical copper shall contain 0.15 to 0.50 per cent of arsenic with the copper plus silver plus arsenic content 99.88 per cent, min. Delete the second sentence of Paragraph (*b*).

Section 5.—Revise to read as indicated above for Section 5 in Tentative Specifications B 21 except that the lot size shall be 10,000 lb.

Section 10.—Delete and renumber the subsequent sections accordingly.

New Section.—Add a new Section 11 to read as indicated above for new Section 14 in Tentative Specifications B 19.

Standard Specifications for Seamless Copper Boiler Tubes (B 13 – 41):

Section 1.—Revise to read "These specifications cover seamless arsenical and nonarsenical copper tubes for locomotive boilers. Arsenical copper will normally be of the type DPA and nonarsenical of the types DHP, DLP or OF of the Tentative Classification of Coppers (A.S.T.M. Designation: B 224)."[2]

Section 2.—In Item (*1*) revise "grade" to read "whether arsenical or nonarsenical."

Section 4.—In Paragraph (*a*) change the value "99.45" to read "99.40" and revise the second sentence to read "The total copper plus silver plus arsenic content shall not be less than 99.88 per cent. In Paragraph (*b*) delete the second sentence.

Section 5 (*a*).—Revise to read as indicated above for Section 5 in Tentative Specifications B 21 except that the lot size shall be "600 tubes or fraction thereof" and portion size "pieces from two individual lengths of the finished product."

New Section.—Add a new Section 13 to read as follows renumbering the subsequent sections accordingly.

> 13. *Methods of Chemical Analysis.*—The chemical compositions enumerated in these specifications shall, in case of disagreement, be determined in accordance with the following methods of the American Society for Testing Materials:
>
> | Test | A.S.T.M. Designation[a] |
> |---|---|
> | Chemical Analysis........ | E 53 and E 62 |
>
> [a] These designations refer to the following methods of testing:
> Standard Method of Chemical Analysis of Copper (Electrolytic Determination of Copper) (A.S.T.M. Designation: E 53),[1] and
> Tentative Photometric Methods for Chemical Analysis of Copper and Copper-Base Alloys (A.S.T.M. Designation: E 62).[1]

New Section.—Add a new Section 14 to read as indicated above for new Section 14 in Tentative Specifications B 19, renumbering subsequent sections accordingly.

Standard Specifications for Seamless Brass Boiler Tubes. (B 14 – 18):

Section 4.—Change the minimum copper content from the present "69.00" to read "68.5" per cent and maximum lead from "0.50" to read "0.07" per cent.

Section 5 (a).—Revise as indicated above for Section 5 (*a*) in Specifications B 13.

New Section.—Add a new Section 12 to read as indicated above for new Section 13 in Specifications B 13, listing only the following tests:

Test	A.S.T.M. Designation[a]
Chemical Analysis.............	E 36

[a] Standard Methods of Chemical Analysis of Brasses (A.S.T.M. Designation: E 36).[1]

New Section.—Add a new Section 13 to read as indicated above for new Section 14 in Tentative Specifications B 19, renumbering subsequent sections accordingly.

Standard Specifications for Free-Cutting Brass Rod and Bar for Use in Screw Machines (B 16 – 47):

Section 4.—Change the required lead content range from the present "2.50 to 3.75" to read "2.5 to 3.7."

Section 5.—Revise to read as indicated above for Section 5 in Tentative Specifications B 21.

Section 8.—Delete and renumber subsequent sections accordingly.

Section 9.—Renumber as Section 8 and delete Paragraph (*b*).

Section 10.—Renumber as Section 9 and in Paragraph (*a*) delete reference to bend test specimens.

New Section.—Add a new Section 11 to read as indicated above for new Section 14 in Tentative Specifications B 19, renumbering the subsequent sections accordingly.

Tables III, IV, V.—Revise to read as shown in the accompanying Tables, V, VI and VII.

Section 12 (b).—Revise as indicated above for Section 12 (*b*) in Tentative Specifications B 21.

Section 14.—Revise as indicated above for Section 15 in Tentative Specifications B 21.

Standard Specifications for Copper-Base Alloys in Ingot Form for Sand Castings (B 30 – 48):

Section 1.—Revise the words "numerical designations" to read "alloy numbers." Make corresponding revisions in Tables I, II and III.

New Section.—Add a new Section 8 to read as indicated above for new Section 14 in Specifications B 19, renumbering subsequent sections accordingly.

Standard Specifications for Copper Pipe, Standard Sizes (B 42 – 47):

Title.—Add the word "seamless" before "copper."

Section 1.—Add "The copper will

normally be of the types DHP, DLP or OF of the Tentative Classification of Coppers (A.S.T.M. Designation: B 224).[2]

Section 5.—Revise as indicated above for Section 5 in Tentative Specifications B 75.

New Section.—Add a new Section 12 to read as indicated above for new Section 14 in Tentative Specifications B 19, renumbering subsequent sections accordingly.

Standard Specifications for Red Brass Pipe, Standard Sizes (B 43 – 47):

Title.—Add the word "seamless" before "red."

Section 4.—Revise the required copper content from the present "83.00 to 86.00" to read "84.0 to 86.0" per cent. Delete tin requirements.

Section 5.—Revise as indicated above for Section 5 in Tentative Specifications B 75.

New Section.—Add a new Section 13 to read as indicated above for new Section 14 in Tentative Specifications B 19, renumbering subsequent sections accordingly.

Standard Specifications for Steam or Valve Bronze Castings (B 61 – 46):

Section 8.—Revise the reference to Fig. 2 to refer to Fig. 1.

New Section.—Add a new Section 10 to read as indicated above for new Section 14 in Tentative Specifications B 19, renumbering subsequent sections accordingly.

Standard Specifications for Composition Brass or Ounce Metal Castings (B 62 – 46):

Section 8.—Revise the reference to Fig. 2 to refer to Fig. 1.

New Section.—Add a new Section 10 to read as indicated above for new Section 14 in Tentative Specifications B 19, renumbering subsequent sections accordingly.

Standard Specifications for Bronze Castings in the Rough for Locomotive Wearing Parts (B 66 – 46):

New Section.—Add a new Section 8 to read as indicated above for new Section 14 in Tentative Specifications B 19, renumbering subsequent sections accordingly.

Standard Specifications for Car and Tender Journal Bearings, Lined (B 67 – 46):

Section 3.—Change the lead content from the present maximum value of "24.0" to read "15.0 to 22.0" per cent.

New Section.—Add a new Section 9 to read as indicated above for new Section 14 in Tentative Specifications B 19, renumbering subsequent sections accordingly.

Standard Specifications for Seamless Copper Tubing, Bright Annealed (B 68 – 47):

Section 1.—Add the word "seamless" before "copper." Revise type designations A, B, and D to read, respectively, DLP, DHP and OF. Make corresponding revisions in Sections 4 and 9. Add a reference to the Tentative Classification of copper (A.S.T.M. Designation: B 224),[2] and indicate that the present designations are being replaced.

Section 5.—Revise as indicated above for Section 5 in Tentative Specifications B 75, except that lot size shall be 5000 lb.

New Section.—Add a new Section 13 to read as indicated above for new Section 14 in Tentative Specifications B 19, renumbering subsequent sections accordingly.

Standard Specifications for Copper Water Tube (B 88 – 48):

Title.—Add the word "seamless" before "copper."

Section 7.—Revise as indicated above for Section 5 in Tentative Specifications B 75.

New Section.—Add a new Section 13 to read as indicated above for new Section 14 in Tentative Specifications B 19, renumbering subsequent sections accordingly.

Section 15.—Renumber as Section 16 and in Paragraph (*b*) revise the value "5" to read "7" per cent.

Standard Specifications for Copper-Silicon Alloy Plate and Sheet for Pressure Vessels (B 96 – 47):

Section 2.—In Item (*1*) revise the term "type" to read "alloy designation," and add a footnote explaining the revision.

Table I.—Revise the term "type" to read "alloy." Delete all zeros in the last right hand place of figures for chemical limits, revise the minimum silicon in type A to read "2.8", the maximum manganese in type C to read "1.2", and the maximum tin in type A to read "0.7" per cent.

Section 5.—Revise to read as indicated above for Section 5 in Tentative Specifications B 21.

New Section.—Add a new Section 8 to read as indicated above for new Section 14 in Specifications B 19, renumbering subsequent sections accordingly.

Section 10.—Renumber as Section 11 and revise the term "types" to read "alloys."

Table II.—Revise the title to read: "Lot Weight Tolerances in Percentage of Theoretical Weight—All Plus."

Table III.—Revise the term "type" to read "alloy" and the alloy designation Nos. 1, 2, etc., to read "A-1, A-2, etc." Delete the column headed "copper". For chemical limits delete all zeros in the last right-hand place of figures. Revise those limits which do not have zeros in the last place as follows, adding for alloy No. 24 a maximum lead content of "0.05" per cent:

Alloy Designation	Silicon, per cent	Iron, per cent	Manganese, per cent	Tin, per cent
No. 1	2.8 to 3.5	0.5 to 1.2	......	......
No. 2	2.8 to 3.2	0.2 max.	......	......
No. 3	2.8 to 3.2	......	......	0.4 to 0.6
No. 4	2.8 to 3.2	......	......	......
No. 5	2.8 to 3.2	......	0.8 to 1.2	......
No. 24	......	......	0.7 to 1.2	......

Standard Specifications for Copper-Silicon Alloy Plate, Sheet and Strip for General Purposes (B 97 – 47):

Section 2.—In Item (*1*) revise the term "type" to read "alloy designation," and add a footnote explaining the revision.

Table I.—Revise as indicated above for Table I in Specifications B 96 and for type B revise the silicon limits to read "0.8 to 2.0" and the maximum manganese to read "0.7" per cent.

Section 5.—Revise to read as indicated above for Section 5 in Tentative Specifications B 21.

Table II.—Revise the term "types" to read "alloys."

New Section.—Add a new Section 10 to read as indicated above for new Section 14 in Tentative Specifications B 19, renumbering subsequent sections accordingly.

Section 11.—Renumber as Section 12 and revise the term "types" to read "alloys".

Tables III and *IV.*—Revise as indicated above for Tables IV and V in Tentative Specifications B 152.

Table V.—Revise to read as shown in the accompanying Table II.

New Table.—Add a new Table VI to read as shown in the accompanying Table III, renumbering subsequent tables accordingly.

Table VIII.—Renumber as Table IX and revise as indicated above for Table III in Specifications B 96 with the following additional changes.

Alloy Designation	Silicon, per cent	Manganese, per cent	Tin, per cent
No. 11	......	......	1.3 to 1.6
No. 12	......	0.10 to 0.50	......
No. 13	1.3 to 1.7	......	......
No. 14	......	0.2 to 0.4	......
No. 15	1.8 to 2.2	......	0.2 to 0.3

above for Section 5 in Specifications B 21.

Table II.—Revise the term "types" to read "alloys".

Section 7.—Delete and renumber subsequent sections accordingly.

TABLE XIV.—DIAMETER TOLERANCES, COLD-DRAWN RODS.

Tolerances are plus and minus unless otherwise indicated: if tolerances all plus or all minus are desired, double the values given.

Diameter or Distance Between Parallel Surfaces, in.	Tolerances, plus and minus, in.			
	Type B		Types A, C and D	
	Round	Hexagonal, Octagonal	Round	Hexagonal, Octagonal
0.150 and under	0.0013	0.0025	0.002	...
Over 0.150 to 0.500, incl.	0.0015	0.003	0.002	0.004
Over 0.500 to 1.00, incl.	0.002	0.004	0.003	0.005
Over 1.00 to 2.00, incl.	0.0025	0.005	0.004	0.006
Over 2.00	0.15 per cent[a]	0.30 per cent[a]	0.20 per cent[a]	0.40 per cent[a]

[a] Expressed to the nearest 0.001 in.

TABLE XV.—THICKNESS TOLERANCES, COLD-DRAWN RECTANGULAR AND SQUARE BARS.

Thickness, in.	Tolerances, plus and minus, for Widths Given, in.					
	½ and under	Over ½ to 1¼, incl.	Over 1¼ to 2.00, incl.	Over 2.00 to 4.00, incl.	Over 4.00 to 8.00, incl.	Over 8.00 to 12.00, incl.
TYPE B ALLOY						
Over 0.188 to 0.500, incl.	0.0035	0.004	0.0045	0.0045	0.006	0.008
Over 0.500 to 1.00, incl.	...	0.0045	0.005	0.005	0.007	0.009
Over 1.00 to 2.00, incl.	...	0.005	0.005	0.006	0.008	...
Over 2.00 to 4.00, incl.	...	...	...	0.30 per cent[a]	...	...
TYPES A, C AND D ALLOY						
Over 0.188 to 0.500, incl.	0.005	0.005	0.006	0.007	0.009	0.012
Over 0.500 to 1.00, incl.	...	0.006	0.007	0.008	0.010	0.013
Over 1.00 to 2.00, incl.	...	0.006	0.007	0.009	0.011	...
Over 2.00 to 4.00, incl.	...	...	...	0.50 per cent[a]	...	...

[a] Expressed to the nearest 0.001 in.

Standard Specifications for Copper-Silicon Alloy Rods, Bars, and Shapes (B 98 – 47):

Section 2.—In Item (*1*) revise the term "type" to read "alloy designation," and add a footnote explaining the revision.

Table I.—Revise as indicated above for Table I in Specifications B 97 and for type D revise silicon limits to read "2.8 to 3.5" per cent.

Section 5.—Revise to read as indicated above for Section 5 in Specifications B 21.

Section 8.—Renumber as Section 7 and delete Paragraph (*b*).

Section 9.—Renumber as Section 8 and in Paragraph (*b*) delete the reference to bend test specimen.

Table III.—Revise to read as shown in the accompanying Table XIV.

Table IV.—Revise to read as shown in the accompanying Table XV.

Table V.—Revise to read as shown in the accompanying Table XVI.

Table VII.—Revise to read as shown in the accompanying Table XI.

New Section.—Add a new Section 10 to read as indicated above for new Section 14 in Tentative Specifications B 19, renumbering subsequent sections accordingly.

Section 11.—Revise Paragraph (*c*) to read as indicated above for Section 12 (*b*) in Tentative Specifications B 21.

TABLE XVI.—WIDTH TOLERANCES FOR COLD-DRAWN RECTANGULAR BARS

Width. in.	Tolerances, plus and minus, in.	
	Type B	Types A, C and D
0.050 and under..................	0.0013	0.0015
Over 0.050 to 0.090, incl.......	0.0015	0.002
Over 0.090 to 0.130, incl.......	0.002	0.003
Over 0.130 to 0.188, incl.......	0.003	0.004
Over 0.188 to 0.500, incl.......	0.0035	0.005
Over 0.500 to 1.25, incl........	0.005	0.007
Over 1.25 to 2.00, incl.........	0.008	0.010
Over 2.00 to 4.00, incl.........	0.012	0.015
Over 4.00 to 12.00, incl........	0.30 per cent[a]	0.50 per cent[a]

[a] Expressed to the nearest 0.001 in.

Section 13.—Revise Paragraphs (*b*) and (*c*) as indicated above for Section 15 (*b*) and (*c*) in Tentative Specifications B 21.

Table IX.—Revise as indicated above for Table VIII in Specifications B 97. Also for alloy No. 31, revise silicon limits to read "2.8 to 3.2" and lead to read "0.2 to 0.5" per cent.

Standard Specifications for Copper-Silicon Alloy Wire for General Purposes (B 99 - 47):

Section 2.—In Item (*1*) revise the term "type" to read "alloy" and add a footnote explaining the revision. Make corresponding revisions in Tables I, II, III, and IV and in the Explanatory Note.

Table I.—Revise as indicated above for Table I in Specifications B 97.

Section 5.—Revise to read as indicated above for Section 5 in Tentative Specifications B 21 except that in portion size "length" shall read "coil."

Tables I and II.—Delete Footnote (*a*).

New Section.—Add a new Section 10 to read as indicated above for new Section 14 in Tentative Specifications B 19, renumbering subsequent sections accordingly.

Table IV.—Revise as indicated above for Table VIII in Specifications B 97.

Standard Specifications for Rolled Copper-Alloy Bearing and Expansion Plates and Sheets For Bridge and Other Structural Uses (B 100 - 47):

Section 1.—Revise the designations type A and type B to read, respectively, alloy No. 1 and alloy No. 2, and add a footnote explaining the revision. Make corresponding revisions in Section 2, Item (*1*), Section 4, and Table I.

Section 4.—For type A revise composition limits to read as indicated above for grade A in Table I in Tentative Specifications B 139. For type B revise chemical limits to read as indicated above for type A in Table I in Specifications B 96.

Section 5.—Revise to read as indicated above for Section 5 in Tentative Specifications B 21, except that sample weight shall be "225 g."

New Section.—Add a new Section 8 to read as indicated above for new Section 14 in Tentative Specifications B 19, renumbering subsequent sections accordingly.

Standard Specifications for Phosphor Bronze Plate, Sheet and Strip (B 103 - 47):

Section 1.—Substitute the term "alloy" for "grade" and make the corresponding revisions in Tables I and II.

Section 2.—In Item (*1*) revise "grade" to read "alloy designation."

Table I.—Revise as indicated above for Table I, in Tentative Specifications B 139 and delete requirements for antimony. For grades B and C revise the phosphorus range from the present "0.03 to 0.25" to read "0.03 to 0.35" per cent.

Section 5.—Revise to read as indicated above for Section 5 in Tentative Specifications B 21 except sample weight shall be "225 g."

Table II.—For grades A, B and B1, revise the maximum tensile strength for extra-hard temper of "98,500" to read "99,000" psi. For Grade C, in the extra-hard, spring and extra-spring tempers, revise "111,500" to read "112,000," "118,500" to read "119,000," and "109,500" to read "110,000" psi.

TABLE XVII.—REVISIONS IN CHEMICAL REQUIREMENTS.

Alloy No.	Copper, per cent	Lead, per cent	Tin, per cent	Iron, per cent	Silicon, per cent	Aluminum, per cent	Manganese, per cent	Zinc, per cent	Sum of Named Elements, min., per cent
2	58.0 to 62.0	1.5 to 2.5	...	...	...	...	...	...	...
4	57.0 to 60.0	...	...	...	...	...	...	...	...
5	57.0 to 61.0	...	...	0.8 to 2.2	...	0.7 max.	...	...	...
6	63.0 to 68.0	...	0.5 max.	...	...	...	...	...	...
7	...	...	0.7 max.	1.6 max.	2.8 to 3.5	...	1.5 max.	1.5 max.	99.5
8	...	...	2.2 max.	0.8 max.	0.7 to 1.7	...	0.7 max.	1.2 max.	99.5
9	...	...	1.5 max.	1.6 max.	2.3 to 3.7	...	1.5 max.	4.2 max.	99.5
10	92.0 to 96.0	...	...	0.5 max.	...	4.0 to 7.0	...	...	99.5

New Section.—Add a new Section 12 to read as indicated above for new Section 14 in Tentative Specifications B 19, renumbering subsequent sections accordingly.

Tables III and IV.—Revise as indicated above for Tables IV and V in Tentative Specifications B 152.

Table V.—Revise to read as shown in the accompanying Tables II and III.

Standard Specifications for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock (B 111 – 48):

Section 1.—Add "Nonarsenical copper will normally be of the types DHP, DLP or OF and arsenical copper will normally be of the type DPA of the Tentative Classification of coppers (A.S.T.M. Designation: B 224).[2]"

Section 2.—Revise Item (*2*) to read: "(*2*) Temper (Section 4)."

Section 4.—Insert a new Paragraph (*b*) to read as follows, relettering the present Paragraph (*b*) as Paragraph (*c*). "(*b*) All tubes other than copper or arsenical copper shall normally be supplied in the annealed condition."

Table I.—For Muntz metal revise the maximum lead requirement from the present "0.3" to read "0.30" per cent. For Admiralty metal revise the tin limits to read "0.9 to 1.2" and maximum lead to read "0.07". For red brass revise the copper content to read "84.0 to 86.0", the maximum lead to read "0.06", and the maximum iron to read "0.05". For aluminum brass revise the copper content to read "76.0 to 79.0", aluminum to read "1.8 to 2.5", and the maximum lead to read "0.07". For 70–30 copper-nickel revise tin to read "1.5 max." For aluminum bronze and copper-nickel alloys, substitute "Copper plus sum of named elements, 99.5 min. per cent" for copper remainder."

Section 6.—Revise as indicated above for Section 5(*a*) in Specifications B 13.

New Section.—Add a new Section 13 to read as indicated above for new Section 14 in Specifications B 19, renumbering subsequent sections accordingly.

Section 14.—In the third line add a reference to Section 9.

Standard Specifications for Copper and Copper-Base Alloy Forging Rods, Bars, and Shapes (B 124 - 48):

Section 1.—Revise alloy designation No. 11 to read "No. 11 *a* and "No. 11 *b*" and make corresponding revisions in Table II in the Appendix.

Section 4.—In Table I revise certain of the limits as shown in the accompanying Table XVII.

Revise requirements for alloy No. 11 to read as follows:

	No. 11*a*	No. 11*b*
Copper, per cent	80.0 to 93.0	78.0 to 85.0
Tellurium, max., per cent	0.6	...
Tin, max., per cent	0.6	0.20
Iron, per cent	4.0 max.	2.0 to 4.0
Silicon, max., per cent	2.2[a]	0.25
Aluminum, per cent	6.5 to 11.0	9.0 to 11.0
Manganese, max., per cent	1.5	1.5
Nickel, per cent	1.0 max.[a]	4.0 to 5.5
Zinc, max., per cent	1.0	...
Sum of named elements, min., per cent	99.5	99.5

[a] When both silicon and nickel are present in the alloy No. 11*a*, only one shall be in excess of 0.25 per cent.

For alloy No. 12, delete "99.90" in the column headed "Sum of Named Elements, min., per cent."

Add a Footnote *c* at the bottom of the table, referenced after the copper content requirement for alloy No. 12, to read "Silver counts as copper."

Section 5.—Revise to read as indicated above for Section 5 in Tentative Specifications B 21.

New Section.—Add a new Section 7 to read as indicated above for new Section 14 in Tentative Specifications B 19, renumbering subsequent sections accordingly.

Section 7.—Renumber as Section 8 and delete the tolerances from Paragraph (*a*), referring to new Tables II and III.

New Tables.—Add new Tables II and III to read as shown in the accompanying Tables XVIII and XIX, renumbering subsequent tables accordingly.

TABLE XVIII.—TOLERANCES ON THE MEAN DIAMETER[a] (FURNISHED AS HOT ROLLED).

Tolerances are plus and minus unless otherwise indicated; if tolerances all plus or all minus are desired, double the values given.

Diameter, in.	Tolerances, plus and minus, in.
0.250 only	0.020[b]
Over 0.250 to 0.375, incl.	0.010
Over 0.375 to 0.750, incl.	0.015
Over 0.750 to 1.25, incl.	0.020
Over 1.25 to 1.50, incl.	0.030
Over 1.50 to 3.00, incl.	1/16
Over 3.00	1/8

[a] The mean diameter of a rod is the average of minimum and maximum diameters, as determined at any one cross-section of the rod.

[b] Tolerances are all plus for a diameter of 0.250 in. only.

TABLE XIX.—TOLERANCES ON DIAMETER OR DISTANCE BETWEEN PARALLEL SURFACES FOR ROUNDS, SQUARES, RECTANGLES, HEXAGONS AND OCTAGONS (FURNISHED AS EXTRUDED).

Tolerances are plus and minus; if tolerances all plus or all minus are desired, double the values given.

Diameter, or Distance Between Parallel Surfaces, in.	Tolerances, plus and minus, in.	
	Alloy Nos. 1, 2, 3, 4, 5, 11*a* and 11*b*	Alloy Nos. 6, 7, 8, 9, 10 and 12
1.00 and under	0.010	0.020
Over 1.00 to 2.00, incl.	0.015	0.030
Over 2.00 to 3.00, incl.	0.025	0.050
Over 3.00 to 3.50, incl.	0.035	0.070
Over 3.50 to 4.00, incl.	0.060	0.120

Standard Specifications for Leaded High-Strength Yellow Brass (Manganese Bronze) Sand Castings (B 132 - 48):

Section 1.—Revise the word "class" to read "alloy." Make corresponding revisions in Sections 4 and 7.

Section 4.—Revise the present elongation requirement "15.0" to read "15."

Section 5.—Change the reference to Fig. 1 to refer to Fig. 2.

New Section.—Add a new Section 7 to read as indicated above for new Section 14 in Specifications B 19, renumbering subsequent sections accordingly.

Section 7.—Renumber as Section 8 and for lead, tin, manganese, aluminum and iron limits in the chemical composition requirements delete the zeros in the last right hand place of figures.

Standard Specifications for Brass Wire (B 134 – 48):

Section 5.—Revise to read as indicated above for Section 5 in Tentative Specifications B 21 except that a lot size of 10,000 lb. shall be used instead of 5000 lb., and in the portion size change "length" to read "coils or reels".

TABLE XX.—SCHEDULE OF LENGTHS (SPECIFIC AND STOCK) WITH ENDS.

Diameter or Distance Beween Parallel Surfaces for Round, Hexagonal, Octagonal Rods and Square Bars, in.	Rectangular Bars, Area[a], sq. in.	Nominal Length, ft.	Shortest Permissible Length[b], per cent of Nominal Length	Maximum Permissible Weight of Ends, per cent of Lot Weight
		TYPE A		
½ and under	0.250 and under	6 to 14, incl.	75	20
Over ½ to 1, incl.	Over 0.250 to 1, incl.	6 to 14, incl.	70	30
Over 1 to 1½, incl.	Over 1 to 2.25, incl.	6 to 12, incl.	60	40
Over 1½ to 2, incl.	Over 2.25 to 4, incl.	6 to 12, incl.	50	45
Over 2 to 3, incl.	Over 4 to 9, incl.	6 to 10, incl.	40	50
		TYPE B		
½ and under	0.250 and under	6 to 12, incl.	65	30
Over ½ to 1, incl.	Over 0.250 to 1, incl.	6 to 12, incl.	60	40
Over 1 to 1½, incl.	Over 1 to 2.25, incl.	6 to 10, incl.	50	50
Over 1½ to 2, incl.	Over 2.25 to 4, incl.	6 to 10, incl.	40	60

[a] Width times thickness, disregarding any rounded corners or edges.

[b] Expressed to the nearest ½ ft.

New Section.—Add a new Section 12 to read as indicated above for new Section 14 in Tentative Specifications B 19, renumbering subsequent sections.

Tables I and II.—Delete Footnote *a*.

Tables V and VI.—In the first column, revise thickness "0.187" to read "0.188."

Standard Specifications for Manganese Bronze Rods, Bars, and Shapes (B 138 – 48):

Section 1.—Delete the words "two types of." Add the letter "s" to "composition," and in the tabulation revise the word "type" to read "alloy."

Section 2.—In Item (*1*) delete the words "type of."

Table I.—Revise "type" to read "alloy." In the chemical limits, with the exception of the lead content, delete the final zero in the last right hand place of figures.

Section 5.—Revise to read as indicated above for Section 5 in Specifications B 21.

Table II.—For type A rods and bars, soft temper, add the tensile requirements of type A shapes soft temper. Revise "type" to read "alloy." Delete the bend test column.

Section 7.—Delete and renumber subsequent sections accordingly.

Section 9.—Renumber as Section 8 and delete Paragraph (*b*).

Section 10.—Renumber as Section 9 and delete the reference in Paragraph (*b*) to bend test specimen.

Tables IV and V.—Revise to read as shown in the accompanying Tables IX and X.

Table VIII.—Revise to read as indicated in the accompanying Table XX.

New Section.—Add a new Section 11 to read as indicated above for new Section 14 in Specifications B 19, renumbering subsequent sections accordingly.

Sections 12(c).—Revise as indicated above for Sections 12(*b*) in Tentative Specifications B 21.

Section 14.—Revise as indicated above for Section 14 in Specifications B 21.

Section 15.—Revise Paragraphs (*b*) and (*c*) as indicated above for Section 15(*b*) and (*c*) in Tentative Specifications B 21.

Standard Specifications for Leaded Red Brass (Hardware Bronze) Rods, Bars, and Shapes (B 140 – 47):

Section 1.—Revise the word "types" to read "alloys."

Section 2.—In Item (*1*) revise the words "type of alloy" to read "alloy designation."

Section 4.—Revise "type" to read "alloy". Delete the final zero in copper limits. For type B revise the maximum nickel content to read "1.2."

Section 5.—Revise to read as indicated above for Section 5 in Tentative Specifications B 21.

New Section.—Add a new Section 10 to read as indicated above for new Section 14 in Specifications B 19, renumbering subsequent sections accordingly.

Tables III, IV and V.—Revise to read as shown in the accompanying Tables V, VI and VII.

Section 10.—Renumber as Section 11 and revise Paragraph (*b*) as indicated above for Section 12 (*b*) in Tentative Specifications B 21.

Section 11.—Renumber as Section 12 and revise Paragraphs (*b*) and (*c*) as indicated above for Section 15 (*b*) and (*c*) in Tentative Specifications B 21.

Standard Specifications for Tin-Bronze and Leaded Tin-Bronze Sand Castings (B 143 – 48),

Standard Specifications for High-Leaded Tin-Bronze Sand Castings (B 144 – 48), and

Standard Specifications for Leaded Red Brass and Leaded Semi-Red Brass Sand Castings (B 145 – 48):

Section 1.—Revise the words "numerical designations" to read "alloy numbers." Make corresponding revisions in Section 2, Item (*1*), Tables I, II and III.

Section 9.—Revise the reference to Fig. 2 to refer to Fig. 1.

New Section.—Add a new Section 12 to read as indicated above for new Section 14 in Tentative Specifications B 19, renumbering subsequent sections accordingly.

Standard Specifications for Leaded Yellow Brass Sand Castings for General Purposes (B 146 – 48):

Revise as indicated above for Specifications B 143 except that Section 9 is to be revised by deleting the phrase "except that Fig. 2 of B 208 is not applicable to these alloys."

Standard Specifications for High-Strength Yellow Brass (Manganese Bronze) and Leaded High-Strength Yellow Brass (Leaded Manganese Bronze) Sand Castings (B 147 – 48):

Section 1.—Revise the words "numerical designations" to read "alloy numbers". Make corresponding revisions in Tables I, II, and III and in Section 2, Item (*1*).

Section 8.—Revise the reference to Fig. 1 to refer to Fig. 2.

New Section.—Add a new Section 11 to read as indicated above for New Section 14 in Tentative Specifications B 19, renumbering subsequent sections accordingly.

Standard Specifications for Aluminum Bronze Sand Castings (B 148 – 48):

Revise as indicated above for Specifications B 147 except that the new section is to be Section 12 and the change in figure references applies to Section 9.

Standard Specifications for Leaded Nickel-Brass (Leaded Nickel-Silver) and Leaded Nickel-Bronze (Leaded Nickel-Silver) Sand Castings (B 149 – 48):

Revise as indicated above for Specifications B 143.

Standard Specifications for Copper-Alloy Condenser Tube Plates (B 171 – 48):

Section 1.—Delete the words "type of."

Section 2.—In Item (*1*) revise the word "type" to read "name."

Table I.—For chemical limits with the exception of lead, iron, and other impurities in naval brass, and other impurities in Muntz and admiralty metal, delete the final zero in the last right hand place of figures. For naval brass revise the copper limits to read "59.0 to 62.0" per cent. For aluminum bronze and for copper-nickel alloy, substitute "Copper plus sum of named elements, 99.5 min. per cent," for "copper remainder." For aluminum bronze, delete accordingly, the requirement "Other impurities, 0.50 max. per cent." For Muntz metal revise the lead limits to read "0.4 to 0.9" per cent. For admiralty metal revise the tin limits to read "0.8 to 1.2" and lead "0.07 max." per cent.

Section 5.—Revise to read as indicated above for Section 5 in Tentative Specifications B 21.

New Section.—Add a new Section 9 to read as indicated above for new Section 14 in Tentative Specifications B 19, renumbering subsequent sections accordingly.

Table III.—Replace the tolerances in the second column with the following: "$\frac{3}{64}$, $\frac{1}{16}$, $\frac{3}{32}$, $\frac{7}{64}$, $\frac{1}{8}$, $\frac{9}{64}$, $\frac{5}{32}$."

Table IV.—Revise the heading of the fourth column to read "Over 60 to 240 in. incl." and delete the next four columns.

Standard Specifications for Silicon-Bronze and Silicon-Brass Sand Castings (B 198 – 48):

Section 1.—Revise the words "numerical designations" to read "alloy numbers." Make corresponding revisions in Tables I and II and Section 2, Item (*1*).

Section 6 (*a*).—Revise by deleting the phrase "except that Fig. 2 of B 208 is not applicable to these alloys."

New Section.—Add a new Section 8 to read as indicated above for new Section 14 in Tentative Specifications B 19, renumbering subsequent sections accordingly.

TENTATIVE REVISIONS OF STANDARDS

The committee recommends revisions of 5 standards for publication as tentative as indicated below:

Standard Specifications for Free-Cutting Brass Rod and Bar for Use in Screw Machines (B 16 – 47):

Table I.—Revise elongation requirements for rounds, hexagons and octagons as follows. The revised column heading will also apply to rectangles and squares:

Present Elongation in 2 in., min., per cent	Revised Elongation min., per cent[a]
20	15
25	20
30	25
7	7
15	10
20	15
25	20
	..
4	4

---

[a] Elongation shall be determined on a gage length of 4 × diameter or thickness of specimen except that in any case a minimum gage length of 1 in. shall be used.

Standard Specifications for Copper-Silicon Alloy Rods, Bars, and Shapes (B 98 – 47):

Table II.—Revise elongation requirements as follows:

Present Elongation in 2 in., min., per cent	Revised Elongation min., per cent[a]
TYPES A, C, AND D ALLOY RODS, SQUARE BARS, AND SHAPES	
45	35
30	25
20	17
25	17
30	17
8	8
14	13
18	13
22	13
7	7
TYPES A, C, AND D ALLOY BARS	
45	35
25	20
25	25
25	27
TYPE B ALLOY RODS, BARS, SHAPES	
35	30
11	11
14	12
17	12
8	8
10	10
12	10
6	6
8	8
10	8

---

[a] Elongation shall be determined on a gage length of 4 × diameter or thickness of specimen except that in any case a minimum gage length of 1 in. shall be used.

Standard Specifications for Manganese Bronze Rods, Bars, and Shapes (B 138 – 48):

Table II.—Revise elongation requirements as follows:

Present Elongation in 2 in., min., per cent	Revised Elongation min., per cent[a]
ALLOY A	
25	20
20	13
20	15
25	17
10	8
15	10
20	16
25	20
ALLOY B	
20	10
12	7
10	5

---

[a] Elongation shall be determined on a gage length of 4 × diameter or thickness of specimen except that in any case a minimum gage length of 1 in. shall be used.

Standard Specifications for Copper Rods for Locomotive Staybolts (B 12 – 47):

Section 6.—Revise present elongation requirements to read:

	Arsenical	Nonarsenical
Revised Elongation, min., per cent[a]	40	35

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[a] Elongation shall be determined on a gage length of 4 × diameter or thickness of specimen except that in any case a minimum gage length of 1 in. shall be used.

Standard Specifications for Leaded Red Brass (Hardware Bronze) Rods, Bars, and Shapes (B 140 – 47):

Table I.—Revise elongation requirements as follows:

Present Elongation in 2 in., min., per cent	Revised Elongation, min., per cent[a]
25	15
8	10
10	10
15	12
10	10
20	12

---

[a] Elongation shall be determined on a gage length of 4 × diameter or thickness of specimen except that in any case a minimum gage length of 1 in. shall be used.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the Tentative Specifications for Bronze Castings for Turntables and Movable Bridges and for Bearing and Expansion Plates of Fixed Bridges (B 22 – 47 T) be approved for reference to letter ballot of the Society for adoption as standard with revisions as indicated:

Section 1.—Substitute the word "alloy" for "class" throughout the section, and make corresponding revisions in Sections 2, 3, 6 and 9.

Section 8 (a).—Revise the reference to Fig. 2 to refer to Fig. 1.

New Section.—Add a new Section 10 to read as indicated above for new Section 14 in Tentative Specifications B 19, renumbering the subsequent sections accordingly.

ADOPTION OF TENTATIVE REVISIONS OF STANDARDS AS STANDARD

The committee recommends the adoption as standard of the tentative revisions issued in 1948 in the following 5 standard specifications:

Standard Specifications for:

- **Copper Rods for Locomotive Staybolts (B 12 – 47),**
- **Free-Cutting Brass Rod and Bar for Use in Screw Machines (B 16 – 47),**
- **Copper-Silicon Alloy Rods, Bars, and Shapes (B 98 – 47),**
- **Manganese Bronze Rods, Bars, and Shapes (B 138 – 48),** and
- **Leaded Red Brass (Hardware Bronze) Rods, Bars, and Shapes (B 140 – 47).**

REPORT OF COMMITTEE B-6
ON
DIE-CAST METALS AND ALLOYS*

Committee B-6 on Die-Cast Metals and Alloys held two meetings during the year: one in Detroit, Mich., on June 23, 1948, and one in Chicago, Ill., on March 2, 1949, with an attendance of 49 and 44, respectively.

Subcommittee III on Tin- and Lead-Base Die-Casting Alloys has been discharged since it has completed its agenda.

There is a balance of $2565.92 in the funds of Committee B-6 as of December 31, 1948.

At the present time, the committee consists of 96 members, of whom 46 are classified as producers, 23 as consumers, and 27 as general interest members.

New Tentative

The committee recommends that the Tentative Specifications for Zinc-Base Alloys in Ingot Form for Die Casting, appended hereto,[1] be accepted for publication as tentative. These specifications have been prepared because of a need for an ingot specification which could be used, especially by the smaller die casting companies, to purchase ingot to make die castings that will conform to the Standard Specifications for Zinc-Base Alloy Die Castings (B 86 - 48). Committee B-6 has been working on this problem for more than a year.

This recommendation has been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

Activities of Subcommittees

Subcommittee II on Zinc-Base Die-Casting Alloys (A. E. Weiss, chairman) prepared the new Tentative Specifications for Zinc-Base Alloys in Ingot Form for Die Casting as covered earlier in this report.

In order that there may be a specification for an appropriate grade of zinc for the new ingot specification, this subcommittee suggests for consideration by Committee B-2, the following footnote for special high-grade zinc in Table I on chemical requirements in the Standard Specifications for Slab Zinc (Spelter) (B 6 - 48): "Special high-grade zinc, when purchased for making zinc-base die castings, shall not exceed 0.005 per cent maximum lead and 0.002 per cent maximum tin. Greater amounts of either lead or tin may constitute cause for rejection."

Subcommittee V on Exposure and Corrosion Tests (W. M. Peirce, chairman) completed plans for the recalling and testing of zinc and magnesium alloy test bars from nine exposure locations after ten years of aging.

The following twenty-one companies have volunteered their services to conduct the mechanical property tests:

American Magnesium Corp.
American Smelting and Refining Co.
Apex Smelting Co.
Bell Telephone Laboratories, Inc.
Bohn Aluminum and Brass Corp.
Canada Bureau of Mines
Chrysler Corp.
Doehler-Jarvis Corp. (tension test bars only)
The Dow Chemical Co.
Ford Motor Co.
Frankford Arsenal

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] These specifications were accepted as tentative by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 2.

[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

General Electric Co.
Hampden Brass and Aluminum Co. (tension test bars only)
The Hoover Co.
National Bureau of Standards
National Lead Co.
The New Jersey Zinc Co.
Sperry Gyroscope Co.
Stewart Die Casting Division (impact test bars from lots assigned to Doehler-Jarvis Corp., and Hampden Brass and Aluminum Co.)
St. Joseph Lead Co.
Westinghouse Air Brake Co.

One more rack of zinc- and magnesium-alloy specimens will remain at each of the exposure locations after this year. These racks were originally exposed for an indefinite period but it is planned to set a definite exposure period for these racks after the data on the ten-year aged specimens are available.

Subcommittee IX on Die-Casting Processes (A. E. Martin, chairman) reported that Task Group D had completed its work on studies of aluminum alloy melting practices and consequently had been discharged. The report of the task group recorded the following conclusions:

1. Soldering to the die was not affected by any of the methods of melting or casting, because no soldering occurred in any case.
2. The surface appearance of all castings was commercially acceptable, although those cast at 1250 F. and above were slightly superior to those cast at lower temperatures. Type of melting and type of furnace did not affect surface appearance.
3. Radiographs indicated some castings had excessive porosity, but this was not related to method of melting, time held, nor casting temperature. Test bars cut from the castings were all commercially acceptable for porosity.
4. Tensile strengths rose slightly with higher casting temperatures. Elongations were not noticeably affected.
5. Tensile strengths and elongations were not affected by method of melting.
6. Quality of the metal was not affected by "stewing" at 1250 F. for 24 hr.

The subcommittee has appointed a special task group whose duty it shall be to draw up a program of work to cover a study of the problems involved in the zinc-alloy die-casting process.

This report has been submitted to letter ballot of the committee, which consists of 96 members, of whom 82 have voted affirmatively and 1 negatively.

Respectfully submitted on behalf of the committee,

J. R. TOWNSEND,
Chairman.

G. L. WERLEY,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee B-6 presented to the Society through the Administrative Committee on Standards the following recommendations:

Revision of Tentative Specifications for:

Aluminum-Base Alloy Die Castings (B 85 - 48 T), and
Copper-Base (Brass) Alloy Die Castings (B 176 - 48 T).

These recommendations were accepted by the Standards Committee on September 22, 1949, and the revised tentative specifications appear in the 1949 Book of A.S.T.M. Standards, Part 2.

Revisions of Tentative Specifications for Magnesium-Base Alloy Die Castings (B 94 - 48 T) were accepted by the Standards Committee on December 14, 1949. The revised tentative specifications appear in the 1949 Book of A.S.T.M. Standards, Part 2.

REPORT OF COMMITTEE B-7

ON

LIGHT METALS AND ALLOYS, CAST AND WROUGHT*

Committee B-7 on Light Metals and Alloys, Cast and Wrought held one meeting during the past year at Atlantic City, N. J., in June, 1948.

During the year, one member was added to the committee and there were two removals. At the present time, the committee consists of 96 members, of whom 77 are voting members; 37 are classified as producers, 29 as consumers, and 11 as general interest members.

During the year, a special subcommittee was set up to carry on the program of tests to determine the corrosion resistance of a number of aluminum and magnesium alloys. This subcommittee will work in cooperation with Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the Annual Meeting, Committee B-7 presented to the Society through the Administrative Committee on Standards the following recommendations:

Revision of Tentative Specifications for:

Aluminum-Base Alloy Sand Castings (B 26 - 47 T),

Aluminum-Base Alloy Permanent Mold Castings (B 108 - 47 T), and

Aluminum-Base Alloys in Ingot Form for Sand Castings, Die Castings, and Permanent Mold Castings (B 179 - 47 T).

Tentative Specifications for:

Aluminum-Alloy Drawn Seamless Tubes for Condensers and Heat Exchangers (B 234 - 48 T),

Aluminum-Alloy Extruded Tubing (B 235 - 48 T), and

Aluminum Bars for Electrical Purposes (Bus Bars) (B 236 - 48 T).

The recommendations for revisions of the three tentatives were accepted by the Standards Committee on September 29, 1948; the new tentatives, Specifications B 234 and B 236 were accepted on December 20, 1948, and Specifications B 235, on December 22, 1948. All, except Specifications B 235, appear in the 1948 Supplement to the Book of A.S.T.M. Standards, Part I-B. Tentative Specifications B 235 - 48 T is published in the compilation of "A.S.T.M. Standards on Light Metals and Alloys."

NEW TENTATIVE

The committee recommends for publication as tentative the proposed Specifications for Aluminum-Alloy Pipe, as appended hereto.[1]

REVISION OF TENTATIVES

The committee is submitting revisions in 12 tentative specifications. The tentatives affected, together with the revisions recommended, are given in detail in the Appendix.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the Tentative Specifications for Aluminum for Use in Iron and Steel Manufacture (B 37 - 46 T)[2] be approved for reference to letter ballot of the Society for adoption as standard with revisions as indicated in the Appendix.

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*Presented at the Fifty-second Annual Meeting of the Society, June 27-July 1, 1949.

[1] These specifications were accepted as tentative by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 2.

[2] 1946 Book of A.S.T.M. Standards, Part I-B.

REAFFIRMATION OF STANDARD

The committee recommends that the Standard Specifications for Magnesium Ingot and Stick for Remelting (B 92 – 45)[2] be reaffirmed and continued in their present status without change.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

ACTIVITIES OF SUBCOMMITTEES

The activities of Subcommittees I, II, III, and IV have culminated in the recommendations for changes in specifications previously noted.

Subcommittee V on Testing of Light Alloys (R. L. Templin, chairman) has appointed a task group to study requirements for frequency of sampling on type and location of specimens in light-alloy wrought products. This subcommittee is also considering the mechanical testing of light metal foil.

Subcommittee VI on Anodic Oxidation of Aluminum and Aluminum Alloys (J. D. Edwards, chairman) is preparing a "Method of Measuring Thickness of Anodic Coatings on Aluminum with the Filmeter."[4] This method is based on a paper, "Measurement of Thickness of Oxide Coatings on Aluminum Alloys,"[5] by Ralph B. Mason and William C. Cochran.

Subcommittee VII on Codification of Light Alloys (R. B. Smith, chairman) is continuing to attempt improvement of the code systems used by A.S.T.M. to designate light alloys. Modifications of the code proposed at the June, 1947, subcommittee meeting are being considered. During the past year the new temper designations adopted by the aluminum industry were incorporated into the tentative specifications for aluminum alloys, and they are being considered for use in the tentative specifications for magnesium alloys.

Special Subcommittee on Atmospheric Exposure Testing (L. H. Adam, chairman) is a new subcommittee organized to carry out the program of atmospheric exposure testing which Committee B-7 has been planning for some time. This subcommittee is actively pushing this corrosion program, and it is expected that a start will be made in the collection of specimens during the coming year.

This report has been submitted to letter-ballot of the committee, which consists of 77 members; 55 members returned their ballots, of whom 51 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

I. V. WILLIAMS,
Chairman.

J. J. BOWMAN,
Secretary.

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[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

[4] See Editorial Note below.

[5] ASTM BULLETIN, No. 148, October, 1947, p. 47.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee B-7 presented to the Society through the Administrative Committee on Standards the following recommendations:

New Tentative Method of:

Test for Thickness of Anodic Coatings by Filmeter Method (B 244 – 49 T).

Revision of Tentative Specifications for:

Aluminum-Base Alloys in Ingot Form for Sand Castings, Die Castings, and Permanent Mold Castings (B 179 – 48 T), and
Aluminum-Base Alloy Permanent Mold Castings (B 108 – 48 T).

These recommendations were accepted by the Standards Committee on September 22, 1949, and the new and revised tentatives appear in the 1949 Book of A.S.T.M. Standards, Part 2.

Revisions of the Tentative Specifications for Magnesium-Base Alloys in Ingot Form for Sand Castings, Die Castings and Permanent Mold Castings (B 93 – 49 T) were accepted by the Standards Committee on December 14, 1949. The revised tentative specifications appear in the 1949 Book of A.S.T.M. Standards, Part 2.

On December 21, 1949, the Administrative Committee on Standards accepted the following recommendations submitted by Committee B-7:

Revision of Tentative Specifications for:

Magnesium-Base Alloy Extruded Round Tubing (B 217 – 48 T),
Magnesium-Base Alloy Sheet (B 90 – 49 T),
Magnesium-Base Alloy Bars, Rods and Shapes (B 107 – 49 T), and
Magnesium-Base Alloy Permanent Mold Castings (B 199 – 47 T).

The revised tentative specifications appear in the 1949 Book of A.S.T.M. Standards, Part 2.

APPENDIX

RECOMMENDATIONS AFFECTING STANDARDS FOR LIGHT METALS AND ALLOYS, CAST AND WROUGHT

In this Appendix are given the recommendations affecting certain standards covering light metals and alloys which are referred to earlier in this report. The standards appear in their present form in the 1946 Book of A.S.T.M. Standards, Part I-B or in the 1947 or 1948 Supplements to Book of A.S.T.M. Standards, Part I-B, except for Tentative Specifications B 235.

Revisions of Tentative Specifications

The committee recommends that the following 12 tentative specifications be revised as indicated below and continued as tentative.

Tentative Specifications for Magnesium-Base Alloy Sand Castings (B 80 - 47 T):

Section 1.—Delete reference to alloys A12 and AZ101 in this section and throughout the specifications. Add a reference to new alloy AZ91.

Sections 5 (a).—Revise to read as indicated for Section 5 (*a*) in Tentative Specifications B 199.

Table I.—Add alloy AZ91 with the following chemical composition requirements:

Aluminum, per cent	8.3 to 9.7
Manganese, min., per cent	0.13
Zinc, per cent	0.4 to 1.0
Silicon, max., per cent	0.3
Copper, max., per cent	0.10
Nickel, max., per cent	0.01
Other Impurities, max., per cent	0.3

For alloy A10 change the required aluminum content from the present "9.0 to 11.0" to read "9.3 to 10.7" per cent.

Table II.—Add tensile requirements for new alloy AZ91 as follows:

Condition	Tensile Strength min., psi.	Yield Strength (0 2 per cent offset), min., psi.	Elongation in 2 in., min., per cent
As cast	18 000	not required	4
Heat treated	34 000	not required	7
Heat treated and aged	34 000	16 000	3

Add tensile requirements for the as-cast and stabilized form of alloys AZ92 and AZ63 as follows:

	Tensile Strength min., psi.	Yield Strength (0.2 per cent offset), min., psi.	Elongation in 2 in., min., per cent
AZ92 (as cast and stabilized)	20 000	11 000	not required
AZ63 (as cast and stabilized)	24 000	11 000	2

Revise the tensile requirements for alloys A8, A10, AZ63, and AZ92 to read as follows:

	Tensile Strength min., psi.
A8 (heat treated)	34 000
A8 (heat treated and aged)	34 000
A10 (heat treated and aged)	34 000
AZ63 (heat treated)	34 000
AZ92 (heat treated)	34 000

Section 8.—Revise as indicated for Section 8 in Tentative Specifications B 199.

Section 9.—Revise to read as follows:

9. (*a*) At least one tension test specimen shall be cast from each melt of 2,000 lb. or fraction thereof to represent the castings poured from the same melt. If the castings are to be heat treated, the specimens shall be heat treated with production castings of the same alloy and in the same condition as the specimens. The specimens shall then be tested to judge the ability of their corresponding melts to respond to the type

of heat treatment to which the specimens were subjected.

(*b*) Each heat treating furnace charge shall include at least one tension test specimen poured from a production melt. Such specimens shall be of the same alloy and in the same condition as the castings, and shall be tested to judge the quality of the heat treating operation given the furnace charge.

Explanatory Notes.—Add the following explanatory note for alloy AZ91:

AZ91.—This alloy has a specific gravity of about 1.81. It should be used for those applications requiring the maximum of strength and hardness as well as ductility. Its mechanical properties in the heat treated and in the heat treated and aged temper are similar to those of AZ63, but its foundry characteristics are similar to AZ92. It should be used in preference to AZ63 if the higher resistance to salt water corrosion of the latter composition is not required.

Table III.—Add the following data to this table for the as-cast and stabilized form of alloys AZ92 and AZ63:

	Typical Yield Strength (0.2 per cent offset), min., psi.	Unit Deformation, inch per inch of gage length
AZ92 (as cast and stabilized).......	17 000	0.0046
AZ63 (as cast and stabilized).......	15 000	0.0043

Tentative Specifications for Magnesium-Base Alloy Sheet (B 90 - 46 T):

Section 1.—Delete reference to alloy AZ51X in this section and throughout the specifications.

Section 8.—Revise to read "One tension test specimen shall be taken to represent each 500 lb. or less, with not less than two test specimens per lot, or such other quantities as may be agreed upon by the manufacturer and purchaser."

Tentative Specifications for Magnesium-Base Alloy Forgings (B 91 - 45 T):

Table I.—For alloy AZ31X revise the zinc content requirement of "0.7 to 1.3" to read "0.6 to 1.4" per cent.

Tentative Specifications for Magnesium-Base Alloys in Ingot Form for Sand Castings, Die Castings and Permanent Mold Castings (B 93 - 47 T):

Section 1.—Delete reference to alloys A12 and AZ101 in this section and throughout the specifications.

Tentative Specifications for Magnesium-Base Alloy Bars, Rods, and Shapes (B 107 - 48 T):

Sections 7 and 8.—Revise to read as follows:

7. (*a*) Tension test specimens shall be a full section of the material or of the type shown in Fig. 1. Small-size specimens with dimensions proportional to those shown in Fig. 1, or a sheet tension specimen of the type shown in Fig. 2, may be used if the size or shape of the material makes it impracticable to use a full section or the standard round specimen.

(*b*) For material $1\frac{1}{2}$ in. or less in diameter or thickness, when not tested in full section, the tension test specimen shall be taken from the center of the section; for material over $1\frac{1}{2}$ in. in diameter or thickness, the specimens shall be taken from midway between the center and the surface. Specimens shall be taken parallel to the direction of extrusion.

8. For extruded bars, rods and shapes having a nominal weight of less than 1 lb. per lineal foot, one tension test specimen shall be taken for each shipment of 500 lb. or less; for larger shipments, an additional specimen shall be taken for each 1000 lb. or fraction thereof in excess of the first 500 lb. For extruded bars, rods and shapes having a nominal weight of 1 lb. or more per lineal foot, one tension test specimen shall be taken for each shipment of 500 ft. or less; for larger shipments, an additional specimen shall be taken for each 1000 ft. or fraction thereof in excess of the first 500 ft. Other procedures for selecting samples may be employed if agreed upon by the manufacturer and the purchaser.

Tentative Specifications for Aluminum and Aluminum-Alloy Sheet and Plate for Use in Pressure Vessels (B 178 - 47 T):

Section 4.—Revise the second sentence to read "A portion shall be taken to represent each 2000 lb. or fraction thereof, of material of a given alloy in the shipment and a sample prepared from each portion."

Table I.—Change the maximum allowable zinc content for alloy GR1 from the present "0.10" to read "0.20" per cent.

Table II.—For alloys A2 and M1 in the as-rolled condition change the present thickness ranges of "0.250 to 0.625" and "0.625 to 2.000" in. to read "0.250 to 0.500" and "0.501 to 2.000" in., respectively.

For alloy M1 in the new thickness range of "0.501 to 2.000" in. add the minimum tensile strength of 15,000 psi.

Section 7.—Revise the last sentence to read "For plate over 1½ in. in thickness, the specimen shall be taken midway between the center and surface of the plate."

TABLE I.—REVISED THICKNESS RANGES AND YIELD STRENGTH VALUES.

Alloy	Temper	Thickness, in.	Yield Strength, psi.
A3........	As-rolled..........	0.250 to 0.500	7 000
A2........	Annealed..........	0.051 to 3.000	3 500
A2........	As-rolled..........	0.250 to 0.500	7 000
A2........	As-rolled..........	0.501 to 2.000	5 000
M1.......	Quarter-hard......	0.051 to 2.000	12 000
M1.......	As-rolled..........	0.250 to 0.500	10 000
M1.......	As-rolled..........	0.501 to 3.000	6 000
GR1......	Annealed..........	0.051 to 3.000	9 500
GR1......	As-rolled..........	0.250 to 0.500	16 000
GR1......	As-rolled..........	0.501 to 3.000	9 500

Section 10.—Revise the first sentence to read "If any test specimen fails to conform to the requirements prescribed in Table II, two additional specimens shall be selected from other sheets or plates in the lot and tested."

Appendix.—Revise certain thickness ranges and yield strength values for the various alloys as outlined in the accompanying Table I. The remainder of the table in the Appendix will remain the same.

Tentative Specifications for Magnesium-Base Alloy Permanent Mold Castings (B 199 - 47 T):

Section 5 (a)—Revise to read as follows:

5. (*a*) The samples for chemical analysis of a melt shall be taken by sawing, drilling, or milling a corresponding casting or tension test specimen in such a manner as to be representative of its average cross-section. If preferred, an analysis specimen may be poured from each melt of 2000 lb. or fraction thereof. The samples shall weigh not less than 50 g.

Table I.—Delete alloy A10X and the column for iron content. For alloy AZ92 change the zinc requirements from the present "1.7 to 2.3" to read "1.6 to 2.4" per cent.

Table II.—Add requirements for the cast and stabilized form of alloy AZ92 as follows:

Tensile strength, min., psi.........	20 000
Yield strength, min., psi...........	11 000
Elongation in 2 in., min., per cent..	not required

Table III.—Add data for the cast and stabilized form of alloy AZ92 as follows:

Yield strength, psi...................	17 000
Unit deformation, in. per inch of gage length..........................	0.0046

Section 8.—Letter the present material as Paragraph (*a*) and delete the second sentence.

Transfer Paragraph (*b*) of Section 9 to Paragraph (*b*) of Section 8 and revise as follows:

(*b*) If any tension test specimen is improperly machined or shows flaws upon testing, it may be discarded and another specimen from the same heat or melt used instead. If no additional specimen is available, the manufacturer and the purchaser shall agree on an alternative procedure.

Section 9.—Revise to read as follows:

9. (*a*) At least one tension test specimen shall be cast to represent not more than 1000 lb. of cleaned castings of the same part number, alloy and condition poured during a period not longer than eight consecutive hours. The specimens shall be poured from melts used for such castings, and if the castings are to be heat treated, the specimens shall be heat treated with production castings of the same alloy and in the same condition as the specimens. The specimens shall then be tested to judge the ability of the metal in the castings they represent to respond to the

type of heat treatment to which the specimens were subjected.

(*b*) Each heat treating furnace charge shall include at least one tension test specimen poured from a production melt. Such specimens shall be of the same alloy and in the same condition as the castings and shall be tested to judge the quality of the heat treating operation given the furnace charge.

Tentative Specifications for Aluminum and Aluminum-Alloy Sheet and Plate (B 209 - 48 T):

Section 4.—Revise the second sentence to read "A portion shall be taken to represent each 2000 lb. or fraction thereof, of material of a given alloy in the shipment and a sample prepared from each portion."

Table I.—Change the maximum allowable zinc content for alloy GR1 from the present "0.10" to read "0.20" per cent. For alloy ZG42 and the core of clad alloy ZG42 change the chromium range from the present "0.15 to 0.40" to read "0.18 to 0.40" per cent.

Table II.—For alloys A2, M1 and GR1 in the annealed temper and in the thickness range of 0.250 to 3.000 in., delete the bend test requirements.

Add the following maximum yield strength requirements for the alloys given for thicknesses to and including 0.500 in. (0.499 in. for clad CG21) of the annealed temper:

Alloy	Yield Strength, max., psi.
CG21	14 000
Clad CG21	14 000
GS21	12 000
Clad CS41	14 000
ZG42	21 000
Clad ZG42	20 000

In Footnote *f* change the present values "56,000" and "60,000" to read "58,000" and "61,000" psi., respectively.

Section 8.—Add the following sentence at the end of Paragraph (*a*): "For plate over 1½ in. in thickness, the specimen shall be taken midway between the center and surface of the plate."

Revise Paragraph (*b*) to read as follows:

> (*b*) *Bend Test Specimens.*—Bend test specimens for sheet shall be the full thickness of the material, approximately ¾ in. in width and, when practicable, at least 6 in. in length. They may be taken in any direction and their edges may be rounded to a radius of approximately $\frac{1}{16}$ in. if desired. For sheet less than ¾ in. in width, the specimens shall be the full width of the material.

Section 11.—Revise the first sentence to read "If any tension test specimen fails to conform to the requirements prescribed in Table II, two additional specimens shall be selected from other sheets or plates in the lot and tested."

Tentative Specifications for Aluminum-Alloy Drawn Seamless Tubing (B 210 - 48 T):

Table I.—Delete alloy CM21 from this table and throughout the specifications.

Change the maximum allowable zinc content for alloy GR1 from the present "0.10" to read "0.20" per cent.

Table II.—For alloy CG21 in the annealed condition change the present maximum tensile strength of "35,000" to read "32,000" psi. and insert a maximum yield strength of "15,000" psi.

For alloy GS21 in the annealed condition insert a maximum yield strength of "14,000" psi.

Section 10.—Revise the first sentence to read "If any tension test specimen fails to conform to the requirements prescribed in Table II, two additional specimens shall be selected from other tubes in the lot and tested."

Section 11 (*b*).—Revise the first sentence to read "Tubes ⅜ to 6 in., exclusive, in outside diameter, in all tempers except annealed, shall not vary in straightness by an amount greater than 0.01 in. times the length of the tube in feet; the variation from straight for tubes 6 in. and more in outside diameter shall not exceed 0.02 in. times the length of the tube in feet.”

TABLE II.—PERMISSIBLE VARIATIONS IN WALL THICKNESS.

Nominal Wall Thickness, in.	Permissible Variations in Wall Thickness, plus or minus, in.			
	Mean[a]	Individual Measurements		
	Alloys CG21, GS21, Round Only	Alloys M1 and GR1, Round Only	Alloys CG21 and GS21, Round Only	All Alloys Other than Round
0.010 to 0.035	0.002	0.002	10 per cent of nominal wall thickness, but not less than 0.003 in.	
0.036 to 0.049	0.003	0.003		
0.050 to 0.120	0.004	0.004		
0.121 to 0.203	0.005	0.005		
0.204 to 0.300	0.008	0.008		
0.301 to 0.375	0.012	0.012		
0.376 to 0.500	0.032	0.032		

[a] Mean wall thickness is the average of the two measurements of wall thickness taken at opposite ends of any diameter.

TABLE III.—PERMISSIBLE VARIATIONS IN WIDTH OR DEPTH OF SQUARE, RECTANGULAR, HEXAGONAL AND OCTAGONAL TUBES.

Nominal Width or Depth, in.	Permissible Variations in Width or Depth, plus or minus, in.		
	At Corners	Not at Corners	
		Square, Hexagonal and Octagonal	Rectangular
0.500 and less	0.003	0.006	The permissible variation in width is the value from column 3 which corresponds to the depth dimension, provided that this value is not less than the permissible variation in width when measured at the corners. The permissible variation in depth is the value from column 3 corresponding to the width dimension, provided that this value is not less than the permissible variation in depth when measured at the corners.
0.501 to 1.00	0.004	0.008	
1.01 to 2.00	0.005	0.010	
2.01 to 3.00	0.006	0.012	
3.01 to 5.00	0.008	0.016	
5.01 to 6.00	0.010	0.020	
6.01 to 8.00	0.015	0.030	
8.01 to 10.00	0.020	0.040	
Over 10.00	0.025	0.050	

Table IV.—Revise Table IV to read as shown in the accompanying Table II.

New Table.—Add a new Table V to read as shown in the accompanying Table III.

Tentative Specifications for Aluminum and Aluminum-Alloy Bars, Rods and Wire (B 211 – 48 T):

Section 1.—Delete the second sentence of Note 1.

Table I.—For alloy CP21 change the requirement for maximum total other elements from the present “0.15” to read “0.20” per cent.

Change the maximum allowable zinc content for alloy GR1 from the present “0.10” to read “0.20” per cent.

For alloy ZG42 change the minimum allowable chromium content from the present “0.15” to read “0.18” per cent.

Table II.—Revise certain physical property values for the various alloys as outlined in the accompanying Table IV. The remainder of the table will remain the same.

Section 7 (b).—Add the following sentence between the present first and second sentences: “In rectangles over $1\frac{1}{2}$ in. in thickness, the specimen also shall be midway between the center and the edge.”

Section 10.—Revise the first sentence to read “If any tension test specimen fails to conform to the requirements prescribed in Table II, two additional specimens shall be selected from other pieces in the lot and tested."

Tentative Specifications for Aluminum and Aluminum-Alloy Extruded Bars, Rods, and Shapes (B 221 – 48 T):

Table I.—Delete alloy ZG43 from this table and throughout the specifications.

For alloy GS2 change the maximum allowable iron content from the present "0.35" to read "0.50" per cent.

For alloy ZG42 change the allowable chromium content range from the present "0.15 to 0.4" to read "0.18 to 0.40" per cent.

Section 7 (b).—Add the following between the first and second sentences: "For rectangles over 1½ in. in thickness, the specimen also shall be midway between the center and the edge. For irregular shapes, the method for obtaining specimens for rectangles shall be approximated as nearly as practicable."

Table II.—Revise certain thickness ranges and physical property values for the various alloys as outlined in the accompanying Table V. The remainder of the table will remain the same.

TABLE IV.—REVISED PHYSICAL PROPERTY VALUES.

Alloy	Temper	Diameter or Thickness, in.	Tensile Strength, psi.	Yield Strength, min., psi.	Elongation in 2 in. or 4× Diam., min., per cent
CP21	T3	1.501 to 2.000	43 000 min.	34 000	12
CP21	T3	2.001 to 3.000	42 000 min.	30 000	14
CM21	O	0.125 and over	35 000 max.	...	16
CG21	O	0.125 and over	35 000 max.	...	16
CG21	T4	0.125 and over	62 000 min.	40 000	14
GS21	T4	0.125 and over	30 000 min.	16 000	18

TABLE V.—REVISED THICKNESS RANGES AND PHYSICAL PROPERTY VALUES.

Alloy	Temper	Thickness, in.	Tensile Strength, psi.	Yield Strength, psi.	Elongation in 4 × Diam., min., per cent
CG21	O	All sizes	35 000 max.	19 000 max.	12.0
CS41	O	All sizes	30 000 max.	18 000 max.	12.0
GS2	T42	Up to 0.500	17 000 min.	10 000 min.	12.0
GS2	T5	Up to 0.500	22 000 min.	16 000 min.	8.0
GS21	O	All sizes	22 000 max.	16 000 max.	16.0
ZG42	O	All sizes	40 000 max.	24 000 max.	10.0
ZG42	T6	Up to 0.249	78 000 min.	70 000 min.	7.0
ZG42	T6	0.250 to 2.999	80 000 min.	72 000 min.	7.0
ZG42	T6	3.000 to 4.499[a]	80 000 min.	70 000 min.	7.0

[a] Cross-sectional area not over 20 sq. in.

Delete the present Footnote *c*, relettering subsequent footnotes accordingly.

Reletter Footnote *g* as Footnote *f* and insert the following sentence to begin the footnote: "Shapes heat treated by the purchaser shall develop a minimum yield strength of 29,000 psi. and are properly designated as T42 temper."

Table III.—Revise Footnote *a* to read as follows: "The permissible variations applicable to a dimension composed of two or more component dimensions is the sum of the permissible variations of the component dimensions if all the component dimensions are indicated."

Section 10.—Revise the first sentence to read "If any tension test specimen fails to conform to the requirements prescribed in Table II, two additional specimens shall be selected from other pieces in the lot and tested."

Section 12.—Delete the words "commercially straight" from the sixth line

Tentative Specifications for Aluminum-Alloy Extruded Tubing (B 235 - 48 T):[1]

Table I.—For alloy GS2 change the maximum allowable iron content from the present "0.35" to read "0.50" per cent.

For alloy ZG42 change the allowable chromium content range from the present "0.2 to 0.4" to read "0.18 to 0.40" per cent.

TABLE VI.—REVISED THICKNESS RANGES AND PHYSICAL PROPERTY VALUES.

Alloy	Temper	Wall Thickness, in.	Tensile Strength, min., psi.	Yield Strength, min., psi.	Elongation in 2 in. or 4 × Diam., min., per cent
CG21	T4	0.109 to 0.499	60 000	40 000	10
CG21	T4	0.500 to 1.499	65 000	46 000	10
CS41	T4	0.109 to 0.499	50 000	30 000	12
CS41	T4	0.500 and over	55 000	35 000	12
GS2*	T42	0.050 to 0.500	17 000	10 000	12
GS2*	T6	0.050 to 0.500	32 000	25 000	8

* This alloy, formerly given the designation GS1, was editorially corrected to GS2 in February, 1949.

Table II.—Revise certain thickness ranges and physical property values for the various alloys as outlined in the accompanying Table VI. The remainder of the table will remain the same.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the following tentative specifications be adopted as standard with revisions as outlined.

Tentative Specifications for Aluminum for Use in Iron and Steel Manufacture (B 37 - 46 T):

Section 1.—Revise to read as follows: "These specifications cover aluminum and aluminum alloy in the form of ingots, rods, or shot, designated as shown in Table I, for use in the manufacture of iron and steel.

Table I.—Delete the present Footnote *a* and revise Note 1 to read "Analysis shall be made only for copper, zinc, magnesium, silicon, and iron unless the determination of additional elements is required by the contract or order or the presence of other elements in substantial concentration is indicated during the course of the analysis. In the latter case, the amount of these other elements shall be determined and the total of copper, zinc, magnesium, silicon and iron, and "other elements" shall not exceed the specified amount prescribed in the last column of the table. Unless otherwise specified in the contract or order, 0.2 per cent of any 'other element' shall constitute a 'substantial amount'."

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[1] Tentative Specifications A 235 - 48 T are issued as a separate reprint and also appear in the compilation of "A.S.T.M. Standards on Light Metals and Alloys," February, 1949.

REPORT OF COMMITTEE B-8
ON
ELECTRODEPOSITED METALLIC COATINGS*

Committee B-8 on Electrodeposited Metallic Coatings held two meetings during the year: one on October 14, 1948, in New York, N. Y. in conjunction with the Fall Congress of the Electrochemical Society and one in Chicago, Ill., on March 4, 1949.

The appointment of Maurice Caldwell as official representative of the American Electroplaters' Society on A.S.T.M. Committee B-8 has been confirmed by the Advisory Committee.

The committee now consists of 144 members of whom 45 are classified as producers, 26 as consumers, 70 as general interest members, and 3 as consulting members.

RECOMMENDATIONS AFFECTING STANDARDS

The committee is presenting for publication a new tentative recommended practice and is recommending revisions in three tentatives, adoption of two tentatives as standard, and the continuation of four tentatives and one standard in their present status without revision. The standards and tentatives affected, together with the revisions recommended, are given in detail in the Appendix.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[1]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Specifications, Papers, and Definitions (J. E. Stareck, chairman) has recommended action on specifications under its jurisdiction as detailed in the Appendix to this report. The revisions of Specifications A 164 and A 165 consist of: (*a*) the addition of a paragraph relative to hydrogen embrittlement; (*b*) deletion of present Section 5 on Selection of Samples and Section 7 on Acceptance and Rejection and substitution of Sections 6, 7, and 10 of Specifications A 166 – 45 T where applicable; (*c*) the addition to Section 6 on Test for Thickness of Coating of a paragraph which permits the use of the magnetic method and dropping tests.

The reasons for these revisions are: (*a*) to warn against dangers of hydrogen embrittlement and to refer to methods for minimizing and removing it; (*b*) it is unlikely that any general schedule of sampling which may now be devised can be consistently applied to the wide variety of articles which may be plated; (*c*) to facilitate testing while still reserving the microscopic method as the effective umpire test. These revisions are also made in the interest of conformity with other specifications under the jurisdiction of Committee B-8.

Subcommittee I recommends the retention of Tentative Specifications A 166, B 142, and B 200 in their present status without revision pending the completion of atmospheric exposure tests now in progress and also recommends the reaffirmation of Standard Specifications B 141 without revision based on the fact that no unfavorable comments have been received since publication in its present form.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

Subcommittee II on Performance Tests (H. A. Pray, chairman) has continued exposure tests of copper-nickel-chromium deposits on high-carbon steel and electro-deposited lead coatings on steel. The report of this subcommittee, including available data on these exposure tests, is appended.[2]

Subcommittee III on Conformance Tests (W. A. Wesley, chairman) recommends the retention of Tentative Methods A 219 in their present status pending the completion of work now in progress under Section A on Thickness Tests. Progress is reported by each of the four active Sections of Subcommittee III engaged in studying thickness tests; porosity tests; adhesion, hardness and ductility tests; and luster tests.

Subcommittee IV on Electroplating Practice (K. M. Huston, chairman) prepared the new Tentative Recommended Practice for the Preparation of High-Carbon Steel for Electroplating, which is appended to this report.[3] Section A (R. M. Wick, chairman) having completed this assignment, has been discharged. Subcommittee IV recommends the adoption as standard, without revision, of the Tentative Recommended Practices B 177 and B 183 because these tentatives have stood without revision for some time, no unfavorable comments having been received since they were published.

Progress is being made by the four active Sections of Subcommittee IV presently engaged in drafting recommended practices for the preparation for plating, and for plating on zinc-base die castings; on copper and copper alloys; on stainless steel; and on aluminum. A new section has been authorized to survey the present status of electroplating on plastics and nonconductors to determine the advisability of preparing a recommended practice.

Subcommittee V on Supplementary Treatments for Metallic Coatings (Marc Darrin, chairman) recommends the retention of Tentative Specifications B 201 as tentative with revisions as detailed in the Appendix to this report.

The revisions of this tentative consist of: (*a*) adding to Section 1 on Scope another note permitting establishment of higher requirements between users and producers after it has been established that they can be met in practice; (*b*) adding to Section 2 on Manufacture a clause which puts restrictions on the removal of a substantial quantity of zinc by the chromate treatment itself; (*c*) adding to this same section a note which emphasizes the importance of quality of zinc coatings and making reference to Tentative Specifications A 164 for minimum thickness requirements; (*d*) inserting in Section 6 on Salt Spray Test for Quality of Coatings a new first paragraph specifying that specimens be aged for a minimum 24 hr. period prior to salt spray testing, and eliminating all parts of this section which call for and comment on scratching through the chromate coating prior to salt spray test.

The reasons for these revisions are: (*a*) to take care of the need for superior finishes; (*b*) to minimize the removal of appreciable quantities of zinc by the chromate treatment, which would seriously impair quality; (*c*) to emphasize the importance of the quality and thickness of the zinc coating to the corrosion resistance of the chromate film; and (*d* because it has been repeatedly demonstrated that freshly formed chromate coatings provide variable and inferior protection in the salt spray. The scratch requirement was eliminated for the following reasons: (*1*) it is difficult to avoid scratching through the zinc coating when it is thin; (*2*) statistics have shown that on zinc coatings failure occurs with substantially the same frequency in the scratches and elsewhere; and (*3*) the salt spray does not leach out hexavalent chromium available in some coatings fast enough to show the protection of scratches found in slower tests.

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[2] See p. 220.

[3] This recommended practice has been accepted as tentative by the Society and appears in the 1949 Book of A.S.T.M. Standards, Part 2.

Subcommittee V has had five sections actively engaged in studying various phases of chromate and phosphate coatings on zinc and cadmium. A sixth section has been organized to study and suggest testing methods for the evaluation of supplementary organic finishes on electrodeposited metallic surfaces.

This report has been submitted to letter ballot of the committee, which consists of 140 voting members; 66 members returned their ballots, of whom 65 have voted affirmatively and 1 negatively.

Respectfully submitted on behalf of the committee,

C. H. SAMPLE,
Chairman.

R. B. SALTONSTALL,
Secretary.

APPENDIX

RECOMMENDATIONS AFFECTING STANDARDS RELATING TO ELECTRODEPOSITED METALLIC COATINGS

In this Appendix are given proposed revisions in certain tentatives relating to electrodeposited metallic coatings which are referred to earlier in this report. The tentatives appear in their present form in the 1946 Book of A.S.T.M. Standards, Part I-B.

Reasons for revisions and recommendations are given in the Annual Report under Activities of Subcommittees.

New Tentative

Tentative Recommended Practice for the Preparation of High-Carbon Steel for Electroplating:

This recommended practice is recommended by Committee B-8 for publication as tentative, as appended hereto.[1]

Revisions of Tentatives

The committee recommends that the following three tentatives be revised as indicated below and continued as tentative.

Tentative Specifications for Electrodeposited Coatings of Zinc on Steel (A 164 - 40 T):[2]

Section 5.—Delete this section and add the following new Sections 5, 6, and 7, renumbering the subsequent sections accordingly:

5. *Hydrogen Embrittlement.*—After plating and any necessary subsequent operations (Note 1) the steel shall be free from the detrimental effects of hydrogen embrittlement. The test methods and their evaluation for freedom from hydrogen embrittlement shall be agreed upon by the manufacturer and purchaser.

Note 1.—Hardened steels and cold worked steels are susceptible to embrittlement by hydrogen in both cleaning and plating operations. This embrittlement should be minimized to the greatest possible extent by careful control of these operations. Embrittlement unavoidably present after plating should be removed by a subsequent treatment such as baking. A procedure for baking to minimize embrittlement is covered in Sections 2 (*b*) and 7 of the Tentative Recommended Practice for the Preparation of High-Carbon Steel for Electroplating (A.S.T.M. Designation: B 000)[1]

6. *Selection of Samples.*—Out of a lot of similar parts, a number of samples shall be selected at random. The size of the lot and the number of samples to be selected shall be agreed upon by the manufacturer and the purchaser. All of the samples selected shall be examined for any defects as given in Section 2.

7. *Number of Tests.*—All of the samples shall be tested for thickness of coating in accordance with Section 8.

Section 6.—Renumber as Section 8 (*a*) and add the following as a new paragraph (*b*).

(*b*) When agreed upon by the manufacturer and purchaser, the thickness of a zinc coating directly on steel may be determined by the magnetic method described in Appendix I or by the dropping test described in Appendix II of the Tentative Methods of Test for Local Thickness of Electrodeposited Coatings (A.S.T.M. Designation: A 219).

Section 7.—Renumber as Section 9 and substitute the following:

(9) *Acceptance and Rejection.*—(*a*) The number of samples permitted to fail in the tests, the number of samples which shall be taken for retest when the first are indecisive, and the number of

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[1] This recommended practice was accepted as tentative by the Society and appears in the 1949 Book of A.S.T.M. Standards, Part 2.

[2] 1946 Book of A.S.T.M. Standards, Part I-B.

samples that may fail in the retest shall be agreed upon by the manufacturer and purchaser.

(*b*) The purchaser shall notify the manufacturer of the rejection of any lot within two weeks of receipt of shipment.

Section 9 (b).—Renumber as Section 11 (*b*) and change the last part of this paragraph to read "Twice the number of parts agreed upon in Sections 6, 7 and 10."

Tentative Specifications for Electrodeposited Coatings of Cadmium on Steel (A 165 - 40 T):[2]

Make the same changes in these specifications as recommended above for Tentative Specifications A 164, substituting "cadmium" for "zinc" where applicable.

Tentative Specifications for Chromate Finishes on Electrodeposited Zinc, Hot-Dipped Galvanized, and Zinc Die-Cast Surfaces (B 201 - 45 T):[2]

Section 1.—Designate the present Note at the end of this section as Note 1 and add the following as Note 2:

> NOTE 2.—This specification is intended to provide a standard of quality for chromate finishes which can be consistently met in good commercial practice. Higher requirements may be established by agreement between users and producers after it has been determined that these can be met in practice.

Section 2.—In the third sentence following the words "chromate treating," insert "as well as the chromate treatment itself." Add the following note to this section:

> NOTE.—The quality, including the purity and thickness of zinc coatings, is known to determine to a large extent the efficacy of any subsequent chromate treatment. The thickness of zinc coatings should be at least that of the lowest grade specified in the Tentative Specifications for Electrodeposited Coatings of Zinc on Steel (A.S.T.M. Designation: A 164) after the chromate treatment has been applied.

Section 6.—Substitute the following for Paragraph (*a*), relettering the present Paragraph (*b*) as (*c*):

> 6. (*a*) *Aging of Specimens.*—Before being tested, specimens shall have been aged at room temperature for at least 24 hr. after treatment.
>
> (*b*) *Preparation of Specimen.*—The surface of the test specimen shall not be cleaned except by wiping with a clean, dry cloth to remove all loose particles.

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following two tentative specifications be approved for reference to letter ballot of the Society for adoption as standard without revision:

Tentative Recommended Practices for:[1]

Chromium Plating on Steel for Engineering Use (B 177 - 45 T), and

Preparation of Low-Carbon Steel for Electroplating (B 183 - 43 T).

TENTATIVES AND STANDARD CONTINUED WITHOUT REVISION

The committee recommends that the following four tentatives and one standard be retained in their present status without revision:

Tentative Specifications for:[1]

Electrodeposited Coatings of Nickel and Chromium on Steel (A 166 - 45 T),

Electrodeposited Coatings of Lead on Steel (B 200 - 45 T), and

Electrodeposited Coatings of Nickel and Chromium on Zinc and Zinc-Base Alloys (B 142 - 45 T).

Tentative Methods of Test for:[1]

Local Thickness of Electrodeposited Coatings (A 219 - 45 T).

Standard Specifications for:[1]

Electrodeposited Coatings of Nickel and Chromium on Copper and Copper-Base Alloys (B 141 - 45).

REPORT OF SUBCOMMITTEE II ON PERFORMANCE TESTS

Note.—This report as preprinted carried tentative conclusions with respect to the copper-nickel-chromium deposits which the committee, on subsequent careful review, felt should be postponed for further consideration when additional data have been obtained. At its meeting in Chicago on October 14, 1949, the committee voted, without dissent (which vote was subsequently confirmed by letter ballot; 76 affirmative, none negative) to withdraw the original report and to substitute the following revised report with the second section containing only data; the conclusions having been referred back to Subcommittee II. This revised report was submitted to the Society through the Board of Directors in accordance with Article 20 of the Regulations Governing Technical Committees and was accepted by the Board on January 17, 1950.

The following report is divided into two parts. One part summarizes the results of the atmospheric exposure of electroplated lead coatings on steel. The other part of the report gives the results of atmospheric exposure of copper-nickel-chromium deposits on high-carbon steel.

Atmospheric Exposure of Electroplated Lead Coatings on Steel

The primary function of electroplated lead coatings on steel is to protect the base metal from corrosion and consequent loss in structural strength. Changes in appearance on weathering are important largely to the extent that they reflect the condition of the base metal. Until the time of the present report, the subcommittee has relied upon the results of visual inspection in evaluating the effectiveness of various lead coatings for the corrosion protection of steel. The results have been useful and the accumulation of visual inspection data is being continued. More direct evidence of coating protection is now available in the form of weight-loss data for the steel itself and data on the change in tensile properties of the base metal. Information on the weathering rate of lead, in the electroplated condition, is also available and has a direct bearing on the problem of corrosion protection by lead coatings.

Visual Inspection:

Table I summarizes the more recent visual inspection data for the specimens of electroplated lead coatings on steel exposed to the atmosphere at New York, N. Y., State College, Pa., Kure Beach, N. C., and Tela, Honduras, for periods up to somewhat over four years. This table may be considered a continuation of Table IV of the 1944 report and Tables I of the 1945, 1946, and 1947 reports.[1]

Since the ratings in the table are based to a considerable extent on the judgement of the inspectors, certain discrepancies appear in the data. It is particularly difficult to distinguish between the "S" rating (percentage of area stained, coating intact) and the "R" rating (percentage of flaky rust of base metal). In spite of the semiquantitative nature of

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 44, p. 280 (1944); Vol. 45, p. 152 (1945); Vol. 46, p. 266 (1946); and Vol. 47, p. 196 (1947).

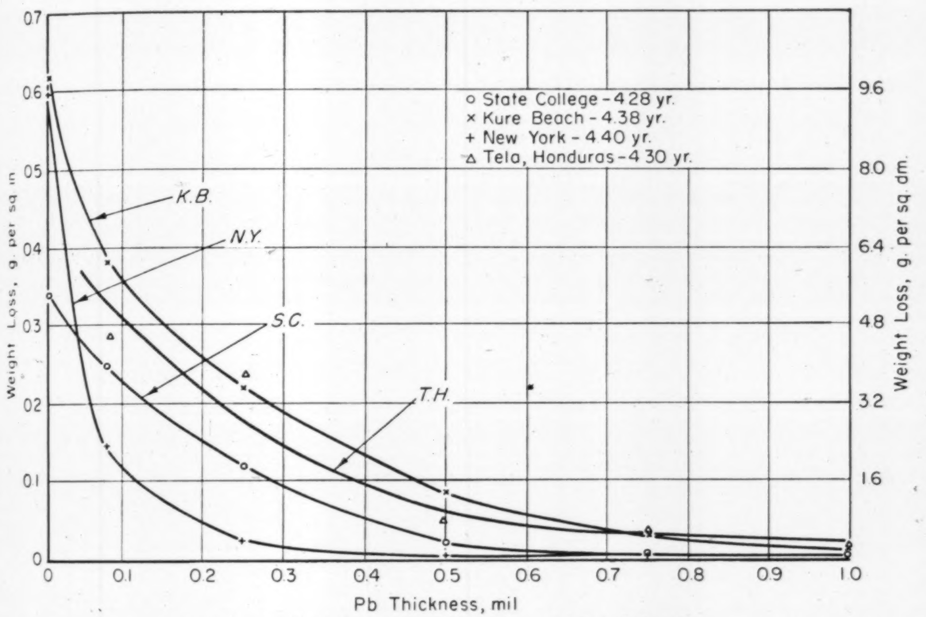

FIG. 1.—Weight Loss *versus* Thickness of Lead Coating.

the data, the trends indicated by earlier inspections appear to be continuing.

From the appearance data, the electroplated lead coatings are generally more protective to steel at New York (industrial atmosphere) than at Kure Beach (seacoast atmosphere). At the other two stations (rural and semitropical), the degree of protection is intermediate.

At all of the exposure stations, the apparent damage to the steel base decreases with increasing coating thickness and, within the limits of the precision of the data, increases progressively with exposure time.

The previously observed retarding effect of a copper undercoating on the rate of deterioration of the steel is apparent in the early stages of rusting, even in the case of the thicker lead coatings. This retarding effect is not observable by visual examination in the later stages of weathering.

Corrosion Damage to Steel as Measured by Weight Loss:

Representative panels were removed from the racks at each of the four exposure stations and stripped of their lead coatings anodically at 15 to 20 amp. per sq. ft. in an electrolyte containing 100 g. per liter NaOH, 75 g. per liter sodium metasilicate, and 50 g. per liter Rochelle salt at a temperature of 180 F. Any rust remaining was then removed by an anodic treatment in 10 per cent sodium cyanide solution at 15 amp. per sq. ft. and at atmospheric temperature. Neither treatment results in a measurable attack on the steel. Knowing the original weight of the uncoated steel panel and the weight of the stripped panel after exposure, the weight loss suffered by the steel panel can be calculated. This is a quantitative measure of damage to the steel base resulting from weathering.

TABLE I.—SUMMARY OF INSPECTION DATA ON THE ATMOSPHERIC EXPOSURE TESTS OF ELECTROPLATED LEAD COATINGS.

	Nominal Coating Thickness, in.	Number of Panels, Averaged Each Station	New York, N. Y.				State College, Pa.			
			Upper Surface		Under Surface		Upper Surface		Under Surface	
			3.45 yr.	4.40 yr.	3.45 yr.	4.40 yr.	3.25 yr.	4.28 yr.	3.25 yr.	4.28 yr.
Sulfamate Pb on steel	0.00050	5	MP-10S	MP-15S	MP-10S	MP-20S	MP-100S-30R	100R	MP	MP-2S
	0.00100	5	....	....	....	MP-<1S	MP-<1S	MP-8S	1P	....
Fluoborate Pb on steel	0.00008	3	100R	100R	MP-100S-65R	MP-100S-2R	100R	100R	100R	100R
	0.00025	5	MP-90S	MP-100S	MP-90S-3R	MP-95S-<1R	100R	100R	MP-100S-70R	MP-100S-90R
	0.00050	5	MP-75S	MP-85S	MP-10S	MP-40S	MP-100S-30R	MP-100S-90R	MP-15S-<1R	MP-30S-1R
	0.00075	5	MP-50S	MP-60S	MP-15S	MP-50S	MP-80S-<1R	MP-95S	....	10P
	0.00100	5	MP-5S	MP-5S	....	MP-20S	MP-5S	MP-45S	....	....
	0.00200	11 to 14	....	....	....	20P	....	....	....	....
Sulfamate Pb on Cu-plated steel	0.00050	5	....	MP	....	MP-8S	MP-10S	MP-50S-8R	MP	MP-2S
	0.00100	5	....	3P	....	10P	MP	MP	5P	4P
Fluoborate Pb on Cu-plated steel	0.00008	3	100R	100R	MP-100S-75R	MP-100S-25R	100R	100R	100R	100R
	0.00025	5	MP-10S	MP-20S	....	MP-10S	MP-100S-95R	100R	MP-40S-2R	MP-80S-10R
	0.00050	5	....	....	....	MP-10S	MP	MP-4S-<1R	MP-1S	MP-8S
	0.00075	5	....	1P	....	MP-3S	MP	MP-<1S	5P	4P
	0.00100	5	....	1P	....	20P	MP	MP-<1S	5P	4P
	0.00200	11 to 14	....	....	....	MP	....	....	....	....
Sulfamate Pb on sheet copper	0.00025	3	....	....	....	....	40S (d)	....	....	....
	0.00050	3	....	....	....	....	....	....	....	....
Fluoborate Pb on sheet copper	0.00025	3	....	....	....	....	30S (d)	....	....	....
	0.00050	3	....	....	....	....	....	....	....	....
Sulfamate Pb-Sn (2 per cent Sn) on steel	0.00100	3	MP-40S	15P	MP-20S	MP	MP-100S-80R	100R	MP-50S-2R	MP-70S-5R
Sulfamate Pb-Sn (10 per cent Sn) on steel	0.00100	3	MP-5S	....	....	15P	MP-100S-30R	MP-98S-30R	....	....
Commercial hot-dipped terne (20 per cent Sn)	0.00017	3	MP-100S	MP-100S	MP-40S	MP-50S	100R	100R	100R	100R
Commerical hot-dipped lead (2.5 per cent Sn, 2 per cent Sb)	0.00040	3	MP-75S	MP-60S	MP-20S	MP-20S	MP-100S-50R	MP-100S-50R	MP-100S-90R	MP-100S-55R
Electroplated zinc on steel	0.00020	3	100R	100R	100R	100R	98R	100R	....	....
Hot-dipped zinc on steel	0.00075	3	100R	100R	MP-80S-40R	MP-98S-8R	....	40R	....	....
Bare Steel	....	6	100R	100R	100R	100R	100R	100R	100R	100R
Fluoborate Pb on steel (damaged)	0.00050	3	Spread	Sl. Spread	....	MP-10S	Bad Spread	100R	MP-100S-1R	MP-50S-1R
	0.00100	3	Spread	V. Sl. Spread	....	MP-<1S	Sl. Spread	Sl.SP	1P	1P
Fluoborate Pb on Cu-plated steel (damaged)	0.00050	3	Sl. Spread	V. Sl. Spread	....	....	Spread	Bad Spread	....	MP-1S
	0.00100	3	Sl. Spread	V. Sl. Spread	....	....	Sl. Spread	V. Sl. Spread	....	....

	Nominal Coating Thickness, in.	Number of Panels, Averaged Each Station	Kure Beach, N. C.				Tela, Honduras	
			Upper Surface		Under Surface		Upper Surface	Under Surface
			3.33 yr.	4.38 yr.	3.33 yr.	4.33 yr.	4.30 yr.	4.30 yr.
Sulfamate Pb on steel	0.00050	5	MP-100S	100R	MP-100S	100R	MP-100S-50R	MP-100S-10R
	0.00100	5	MP-25S	MP-60S-35R	MP-1S	MP-5S	MP-80S-10R	MP-2S
Fluoborate Pb on steel	0.00008	3	100R	100R	100R	100R	100R	100R
	0.00025	5	MP-100S-70R	100R	MP-100S-30R	100R	100R	MP-100S-50R
	0.00050	5	MP-100S-5R	100R	MP-100S-5R	100R	N.D.	N.D.
	0.00075	5	MP-100S	100R	MP-100S	100R	MP-100S-10R	MP-10S-1R
	0.00100	5	MP-95S	MP-100S-98R	MP-75S	MP-85S-65R	MP-95S-2R	MP-2S
	0.00200	11 to 14	MP-<1S	MP-3S	MP-<1S	MP-3S	MP	...
Sulfamate Pb on Cu-plated steel	0.00050	5	MP-100S	100R	MP-60S	MP-80S-40R	MP-40S-5R	MP-70S-5R
	0.00100	5	MP-5S	MP-25S-2R	MP-2S	MP-6S	MP-30S-2R	MP
Fluoborate Pb on Cu-plated steel	0.00008	3	100R	100R	100R	100R	100R	100R
	0.00025	5	MP-100S-75R	100R	MP-100S-20R	100R	100R	MP-100S-50R
	0.00050	5	MP-90S-10R	MP-100S-98R	MP-30S	MP-45S-20R	MP-20S-5R	MP-40S-5R
	0.00075	5	MP-70S-<1R	MP-75S-55R	MP-3S	MP-5S	N.D.	N.D.
	0.00100	5	MP-65S	MP-50S-3R	MP-8S	MP-20S	MP-20S-<1R	MP-2S
	0.00200	11 to 14	MP-<1S	MP-1S	MP-<1S	MP-1S	MP-2S	1P
Sulfamate Pb on sheet copper	0.00025	3	50S (d)	100S (d)	5S (d)	20S (d)	N.D.	N.D.
	0.00050	3	....	MP	....	2S (d)	N.D.	N.D.
Fluoborate on sheet copper	0.00025	3	30S (d)	100S (d)	25S (d)	40S (d)	N.D.	N.D.
	0.00050	3	....	MP	....	1S	N.D.	N.D.
Sulfamate Pb-Sn (2 per cent Sn) on steel	0.00100	3	MP-100S	100R	MP-100S	MP-100S-75R	N.D.	N.D.
Sulfamate Pb-Sn (10 per cent Sn) on steel	0.00100	3	MP-100S	100R	MP-20S	MP-55S	N.D.	N.D.
Commercial hot-dipped terne (20 per cent Sn)	0.00017	3	100R	100R	100R	100R	N.D.	N.D.
Commercial hot-dipped lead (2.5 per cent Sn, W per cent Sb)	0.00040	3	MP-100S-40R	100R	MP-100S-20R	100R	N.D.	N.D.
Electroplated zinc on steel	0.00020	3	100R	100R	7R	20R	N.D.	N.D.
Hot-dipped zinc on steel	0.00075	3	....	....	....	....	N.D.	N.D.
Bare steel	....	6	100R	100R	100R	100R	100R	100R
Fluoborate Pb on steel (damaged)	0.00050	3	100R	100R	MP-100S	100R	N.D.	N.D.
	0.00100	3	Bad Spread	Bad Spread	MP-3S	MP-10S-2R	N.D.	N.D.
Fluoborate Pb on Cu-plated steel (damaged)	0.00050	3	Bad Spread	Bad Spread	MP-50S	MP-80S-30R	N.D.	N.D.
	0.00100	3	Spread	Sl. Spread	MP-<1S	MP-7S	N.D.	N.D.

Abbreviations and symbols used: P—Number of pinholes, up to 25; MP—pinholes, more than 25; S—percentage of area stained, coating intact; R—percentage of flaky rust of base metal; **Sl.—slight; (d)** = dark; N.D. = no data.

Note.—Thickness of copper plate in all cases, 0.000015 in.

TABLE II.—STEEL CORROSION FROM WEIGHT LOSS OF STRIPPED PANELS.

Nominal Coating Thickness, in.	New York (4.40 yr.)		Kure Beach (4.38 yr.)		State College (4.28 yr.)		Tela, Honduras (4.30 yr.)	
	Panel No.	Weight Loss, g.	Panel No.	Weight Loss, g.	Panel No.	Weight Loss, g.	Panel No.	Weight Loss, g.
BARE STEEL								
None.....	620	27.93	617	27.30	618	17.53	...	....
None.....	624	29.77	622	32.43	619	15.39	...	....
SULFAMATE LEAD ON BARE STEEL								
0.00050...	24	0.05	22	4.60	19	1.98	16	5.75
0.00100...	48	0.03	46	0.84	43	0.01	40	0.52
FLUOBORATE LEAD ON BARE STEEL								
0.00008...	780	4.97	778	17.01	775	10.12	779	14.12
0.00025...	72	2.09	70	9.32	67	5.74	64	10.03
0.00050...	96	0.03	94	5.08	...	....	...	....
0.00075...	132	0.03	130	2.68	127	0.50	124	1.69
0.00100...	156	0.02	154	1.54	151	0.01	148	0.62
SULFAMATE LEAD ON CU-PLATED STEEL								
0.00050...	264	0.04	262	3.32	259	1.15	256	1.11
0.00100...	288	0.02	286	0.01	283	0.00	280	0.08
FLUOBORATE LEAD ON CU-PLATED STEEL								
0.00008...	804	8.79	802	19.43	799	13.84	803	13.50
0.00025...	312	0.14	310	11.58	307	5.42	304	13.40
0.00050...	336	0.04	334	3.27	331	0.10	328	1.06
0.00075...	372	0.03	370	0.30	367	0.02	...	....
0.00100...	396	0.03	394	0.09	391	0.01	388	0.09

Steel weight-loss data are listed in Table II. The weight losses, averaged for a given coating thickness without regard to undercoating or type of plating bath, are plotted in Fig. 1 as a function of coating thickness. The data confirm the results of visual inspection and lead to the following generalizations:

1. The various atmospheres result in a wide variation in the protectiveness of lead coatings. As indicated from visual observation, much less damage occurs to coated steel exposed at New York than at the other stations within the range of coating thickness represented in the tests. The seacoast atmosphere at Kure Beach is most severe with respect to the deterioration of steel under lead coatings.

2. The corrosivity of an atmosphere toward bare steel bears no direct relationship to the effectiveness of lead coatings at approximately 4.3 yr. exposure. The corrosion rate for steel at New York is nearly twice that at State College, whereas the damage to lead-coated steel is a great deal less at New York.

3. As indicated by visual inspection, damage to the steel base is an inverse function of coating thickness at all locations.

4. The protectiveness of lead coatings is directly related to the corrosion rate for lead in the various atmospheres (see Table IV and Fig. 3 for data on lead corrosion).

5. The thickness of lead required to protect steel for a given time period varies with the exposure location. Thus to avoid steel corrosion of more than 0.1 g. per sq. in. (1.6 g. per sq. dm.) for approximately 4.3 yr. requires a coating thickness of about 0.1 mil at New York, 0.3 mil at State College, 0.4 mil at Tela, and 0.5 mil at Kure Beach.

The effect of a copper plate (0.000015 in.) on steel as a base for electroplated lead is shown in Fig. 2. In the case of the thicker, more protective coatings, after approximately 4.3 yr. exposure, the copper undercoat is definitely beneficial at all locations. The results of earlier visual examination indicate that this is also true for the thinner coatings in the initial stages of deterioration. At coating thicknesses that permit appreciable attack on the steel, the copper film appears to accelerate the steel corrosion rate. This behavior undoubtedly results from the electrode potential relationships for the three metals involved.

Corrosion Damage to Steel as Measured by Change in Tensile Strength:

Two sheet tension test specimens, with standard 0.500-in. reduced section, were cut from each of the panels used for weight-loss determinations. The results of elongation, yield strength, and tensile strength determinations are given in

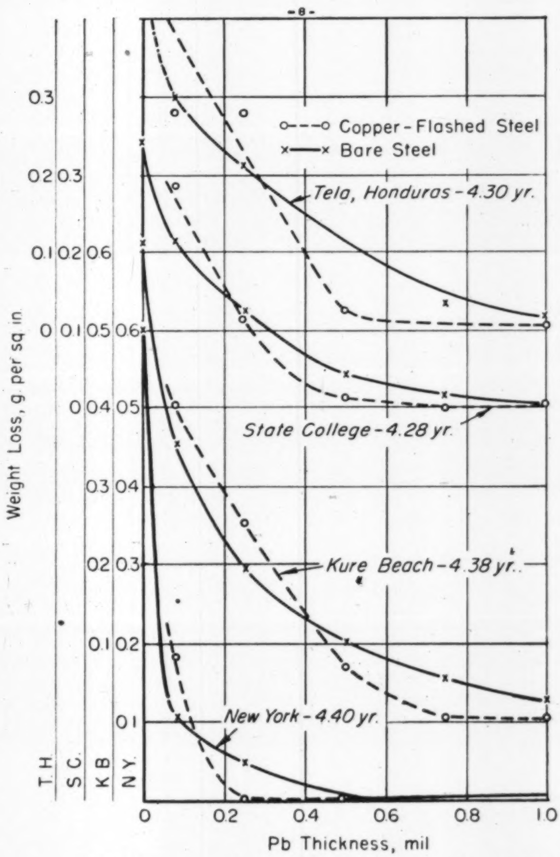

FIG. 2.—Weight Loss of Steel *versus* Thickness of Lead Coating.

Table III. Although the precision of the measurement of tensile properties is of a different order of magnitude than the weight-loss determinations, the results emphasize and confirm the conclusions arrived at by the more precise weight-loss method of estimating damage to the steel base.

Corrosion Rate of Lead:

By stripping the lead corrosion products from heavily lead-plated (0.002-in.) panels after periods of exposure that did not cause rusting of the steel and determining the loss in weight of the lead, a quantitative measure of the rate of corrosion of electroplated lead has been obtained. The weight loss, average thickness loss, and the average penetration rate for lead are given in Table IV. The data are shown graphically in Fig. 3.

The corrosion rate for lead decreases somewhat with time of exposure and is highly dependent upon the type of atmosphere to which it is exposed.

At New York, where the protectiveness of lead coatings is highest, the rate of corrosion of electroplated lead is lowest. At Kure Beach, where the corrosion rate for lead is high, the protection offered to steel by lead coatings is least. State College and Tela occupy intermediate positions in both respects.

There is thus a strikingly direct relationship between the protective value of lead coatings at the various exposure stations and the rate at which lead corrodes in those same atmospheres.

The subcommittee intends to continue the visual inspection of the test panels and to remove panels periodically for steel weight-loss and tensile property data.

ATMOSPHERIC EXPOSURE OF COPPER-NICKEL-CHROMIUM DEPOSITS ON HIGH-CARBON STEEL

During the past several years, Subcommittee II has been concerned with a study of the atmospheric corrosion behavior of composite copper-nickel-chromium coatings on high-carbon steel. In the spring of 1946, an exploratory set of panels was exposed at three stations. On the basis of the experience gained from the exploratory tests, certain of the panel preparation techniques were revised and a method of rating and recording the behavior of the coatings was developed. A more comprehensive program, described here, was then under-

TABLE III.—STEEL CORROSION FROM TENSILE PROPERTIES OF STRIPPED PANELS.

NOTE.—Tensile properties calculated on the basis of original steel thickness.
Values are the average of data from two standard sheet tensile specimens from each panel.
Original properties from lead-coated, stored, and stripped panels:
Elongation in 2 in., 28.5 per cent
Yield Strength, 45,200 psi.
Ultimate Tensile Strength, 54,150 psi.

Nominal Coating Thickness, in.	New York (4.40 yr.)							Kure Beach (4.38 yr.)						
	Panel No.	Elongation		Yield Strength		Tensile Strength		Panel No.	Elongation		Yield Strength		Tensile Strength	
		per cent	per cent Change	psi.	per cent Change	psi.	per cent Change		per cent	per cent Change	psi.	per cent Change	psi.	per cent Change
BARE STEEL														
None	620	11.5	−73.0	24 700	−43.0	33 300	−37.8	617	15.5	−47.4	30 100	−33.2	38 100	−30.9
None	624	12.5		26 800		34 000		622	14.5		28 600		36 700	
SULFAMATE LEAD ON BARE STEEL														
0.00050	24	25.0	−12.3	43 750	−3.2	52 800	−2.5	22	25.0	−12.3	40 200	−11.0	49 800	−8.0
0.00100	48	30.0	+5.3	45 400	+4.4	52 800	−2.5	46	24.0	−15.8	43 900	−2.9	53 000	−2.1
FLUOBORATE LEAD ON BARE STEEL														
0.00008	780	19.5	−31.6	41 300	−8.6	50 400	−6.9	778	15.5	−45.6	31 800	−29.6	41 400	−23.6
0.00025	72	22.5	−21.0	43 100	−4.6	52 000	−4.0	70	26.0	−8.8	37 300	−17.5	47 600	−12.1
0.00050	96	27.5	−3.9	44 600	−1.3	54 000	−0.3	94	18.0	−36.8	39 300	−13.0	48 600	−10.2
0.00075	132	28.0	−1.7	46 600	−1.3	53 900	−0.5	130	26.0	−8.8	44 400	−1.8	43 500	−19.7
0.00100	156	28.0	−1.7	45 600	+8.9	53 900	−0.5	154	27.0	−5.3	43 300	−4.2	52 300	−3.4
SULFAMATE LEAD ON CU-PLATED STEEL														
0.00050	264	23.0	−19.3	44 000	−2.7	53 100	−1.9	262	24.5	−14.0	40 000	−11.5	50 100	−7.5
0.00100	288	27.0	−5.3	44 500	−1.5	54 150	0	286	23.5	−17.5	42 600	−5.7	52 200	−3.6
FLUOBORATE LEAD ON CU-PLATED STEEL														
0.00008	804	23.5	−17.0	38 400	−15.0	48 100	−11.1	802	14.0	−50.9	30 300	−32.9	39 700	−26.6
0.00025	312	26.0	−8.8	45 100	−2.4	53 500	−1.2	310	22.5	−21.0	37 100	−17.9	46 700	−13.7
0.00050	336	28.5	0	43 200	−4.4	53 100	−0.2	334	20.0	−29.8	39 600	−12.4	48 300	−10.8
0.00075	372	24.0	−15.8	43 200	−4.4	52 800	−2.5	370	20.0	−29.8	41 100	−9.1	50 100	−7.5
0.00100	396	25.0	−12.3	45 500	+6.6	53 300	−1.6	394	23.5	−17.5	44 800	−0.9	53 300	−1.6

TABLE III—*Continued.*

Nominal Coating Thickness, in.	State College (4.28 yr.)							Tela, Honduras (4.30 yr.)						
	Panel No.	Elongation		Yield Strength		Tensile Strength		Panel No.	Elongation		Yield Strength		Tensile Strength	
		per cent	per cent Change	psi.	per cent Change	psi.	per cent Change		per cent	per cent Change	psi.	per cent Change	psi.	per cent Change
Bare Steel														
None	618	19.5	−32.4	34 000	−25.3	43 600	−19.3	...	....	....	....	....	....	....
None	619	19.0		33 500		43 800		...	....	....	....	....	....	....
Sulfamate Lead on Bare Steel														
0.00050	19	19.0	−33.3	42 300	−6.4	51 100	−5.6	16	20.0	−29.8	40 700	−9.9	48 700	−10.1
0.00100	43	25.0	−12.3	44 000	−2.7	53 000	−2.1	40	28.5	0.0	44 200	−2.2	52 300	−3.4
Fluoborate Lead on Bare Steel														
0.00008	775	22.5	−21.0	37 300	−17.5	47 300	−12.6	779	18.0	−36.8	37 200	−17.7	45 400	−16.1
0.00025	67	27.5	−3.5	40 400	−10.6	50 100	−7.5	64	23.0	−19.3	38 400	−15.0	47 300	−12.6
0.00050	...	....	....	....	....	....	....	...	....	....	....	....	....	....
0.00075	127	27.5	−3.5	44 100	−2.4	53 800	−0.6	124	26.0	−8.8	42 900	−5.1	51 200	−5.4
0.00100	151	32.0	+12.3	43 700	−3.3	52 700	−2.7	148	27.0	−5.3	44 100	−2.4	52 600	−2.9
Sulfamate Lead on Cu-Plated Steel														
0.00050	259	22.0	−22.8	43 600	−3.5	53 000	−2.1	256	19.0	−33.3	42 100	−6.9	50 500	−6.7
0.00100	283	27.5	−3.5	43 800	−3.1	53 100	−1.9	280	30.0	+5.3	44 900	−0.7	53 300	−1.6
Fluoborate Lead on Cu-Plated Steel														
0.00008	799	17.0	−40.0	34 400	−23.8	44 300	−18.2	803	19.0	−33.3	35 500	−21.4	43 000	−20.3
0.00025	307	29.0	+1.8	40 800	−9.7	50 400	−6.9	304	21 0	−26.3	38 400	−15.0	45 300	−16.3
0.00050	331	29.5	+3.5	44 100	−2.4	53 600	−1.0	328	20.5	−28.1	40 700	−9.0	49 700	−8.2
0.00075	367	30.5	+7.0	43 700	−3.3	53 300	−1.6	...	...	....	..	....	....	....
0.00100	391	23.0	−19.3	44 300	−2.0	53 000	−2.1	388	27.5	−3.5	44 400	−1.8	53 100	−1.9

TABLE IV.—ATMOSPHERIC CORROSION OF ELECTROPLATED LEAD.

Note.—Values are the average of data from six panels.

Exposure Time, yr.	Initial Deposit Weight, g.	Loss in Deposit Weight, g.	Average Loss in Deposit Thickness, in.	Average Penetration, in. per yr.
New York, N. Y.				
2.40	16.93	0.59	0.000066	0.000028
3.45	16.64	0.85	0.000095	0.000027
4.40	17.71	0.98	0.000109	0.000025
Kure Beach, N. C.				
2.38	16.96	1.87	0.000210	0.000088
3.33	16.61	2.36	0.000260	0.000078
4.38	18.09	2.82	0.000317	0.000072
State College, Pa.				
2.28	17.14	1.51	0.000169	0.000074
3.25	16.85	1.67	0.000206	0.000063
4.28	17.11	2.11	0.000236	0.000055
Tela, Honduras				
2.27	17.18	1.52	0.000170	0.000075
4.30	16.71	2.28	0.000254	0.000060

taken and plated panels were exposed at five stations in April, 1947. The purpose of the tests was to determine the relative usefulness of various composite copper-nickel-chromium electrodeposits as protective and decorative coatings in various typical atmospheres on high-carbon steel of the type used for automobile bumpers, in so far as this can be determined from tests of this type.

Plan of the Tests:

An outline of the thickness, plating, and buffing variations included in the tests is shown in Table V. The variables include the total plate thickness, nickel thickness, copper undercoat thickness, buffing of undercoat, type of nickel plate, heat treatment of the nickel deposit, type of steel base, and, in a limited way,

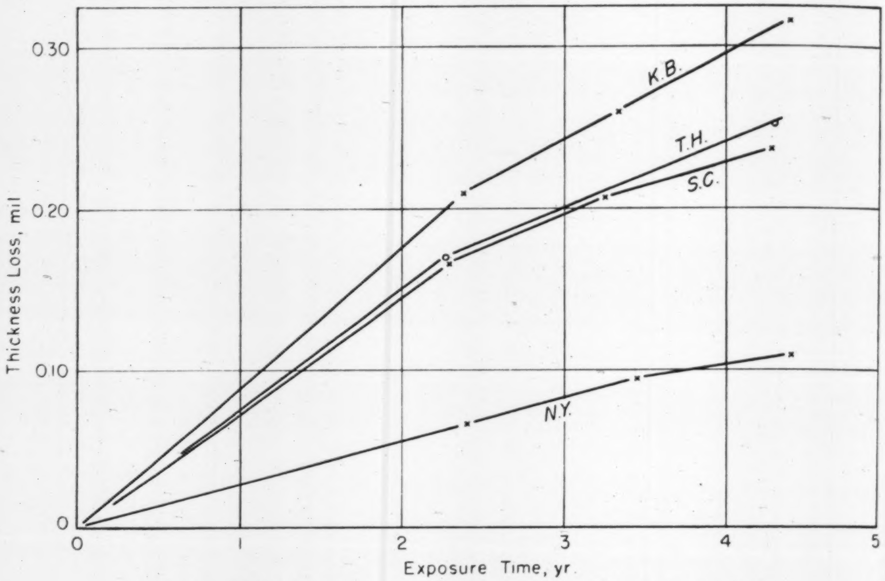

FIG. 3.—Thickness Loss of Lead Coating *versus* Exposure Time.

the polishing procedure for the steel. The atmospheric exposure sites were selected to include varied and typical atmospheres. They were: (1) New York (Bell Telephone Laboratories, industrial); (2) Kure Beach, N. C. (seacoast); (3) Pittsburgh, Pa. (Bureau of Mines, heavy industrial); (4) State College, Pa. (rural); and (5) Coral Gables, Fla. (semitropical, inland, suburban). A sixth site, Detroit, Mich. (General Motors Research Laboratory) where the prevailing industrial atmosphere could be supplemented by thrice-weekly application of salt solution to simulate winter road conditions, was also included.

Preparation of Test Panels:

All panels were prepared by the Standard Steel Spring Co. at their Coraopolis plant in a specially designed small-scale plating line using special tanks, racks, and buffing and polishing equipment. The primary aim in the panel preparation program was to produce test panels representing good commercial plating practice and conforming to the intended plate characteristics.

The source and analysis of the steel used are given in Table VI.

The analyses are typical of materials used in hot and cold forming of parts to be plated.

The S.A.E. 1095 stock in the form of 4 by 6 in. panels was heated to a temperature of 1500 to 1590 F., flattened at temperature between dies in an hydraulic press, air quenched, and subsequently drawn at 970 F. to a Brinell hardness of approximately 330.

Both types of steel were polished by hand on a belt grinder with alumina grit belts. The polishing grit sequence was: 100, 120, 150 dry, 150 grease. Profilometer data were taken from polished steel panels as a check on the uniformity of the operation. In the case of lot 34, the above sequence was followed by 240 grease and 320 grease.

Buffing of the deposits, where indicated, was accomplished on a specially

TABLE V.—PLATE THICKNESS AND TYPE.

Note.—(b) = buffed; (ba) = buffed and annealed; (WA) = wetting agent present; (pH) = high-pH bath. All panels include a final chromium coating 0.00001 in. thick.

Lot	Cyanide Copper, mils	Acid Copper, mils	Total Copper, mils	Dull Nickel, mils	Buffed Dull Nickel, mils	Buffed Semi-bright Nickel, mils	Bright Nickel, mils	Total Thickness, mils	Steel (S.A.E. No.)	Steel Finish
No. 1	...	...	...	...	1.0			1.0	1095	Polished
No. 2	0.1	...	0.1	...	0.9			1.0		
No. 3	0.1	0.4	0.5	...	0.5			1.0		
No. 4	0.1	0.4(b)	0.5	...	0.5			1.0		
No. 4NA	...	...	...	0.5(b)	0.5			1.0		
No. 4B	...	...	...	0.5(ba)	0.5			1.0		
No. 5X	...	...	...	...	1.0(pH)			1.0		
No. 6X	0.1	...	0.1	...	0.9(pH)			1.0		
No. 5	...	...	...	...	1.5			1.5	1095	Polished
No. 6	0.1	...	0.1	...	1.4			1.5		
No. 7	0.1	0.4	0.5	...	1.0			1.5		
No. 8X	0.1	0.9	1.0	...	0.5(WA)			1.5		
No. 9	0.1	0.9(b)	1.0	...	0.5			1.5		
No. 9NA	...	...	...	1.0(b)	0.5			1.5		
No. 10	...	...	...	...	2.0			2.0	1095	Polished
No. 11	0.1	...	0.1	...	1.9			2.0		
No. 12	0.1	0.4	0.5	...	1.5			2.0		
No. 13	0.1	0.9	1.0	...	1.0			2.0		
No. 14	0.1	0.9(b)	1.0	...	1.0			2.0		
No. 14NA	...	...	...	1.0(b)	1.0			2.0		
No. 14B	...	...	...	1.0(ba)	1.0			2.0		
No. 15	0.1	1.4	1.5	...	0.5			2.0		
No. 16	0.1	1.4(b)	1.5	...	0.5			2.0		
No. 10X	...	...	...	...	3.0			3.0	1095	Polished
No. 14X	0.1	0.9	1.0	...	2.0			3.0		
No. 16X	0.1	1.4	1.5	...	1.5			3.0		
No. 25	...	...	...	...	1.5			1.5	9112	Polished
No. 26	0.1	...	0.1	...	1.4			1.5		
No. 27	0.1	0.4	0.5	...	1.0			1.5		
No. 28	...	...	...	...	...	2.0		2.0	1095	Polished
No. 29	0.1	0.9	1.0	...	...	1.0		2.0		
No. 29A	...	...	...	...	1.0	1.0		2.0		
No. 30	0.1	0.9	1.0	...	...	...	1.0	2.0	1095	Polished
No. 31	0.1	0.9(b)	1.0	...	...	...	1.0	2.0		
No. 32	0.1	...	0.1	0.9	...	...	1.0	2.0		
No. 33	0.1	...	0.1	...	0.9	...	1.0	2.0		
No. 34	0.1	...	0.1	0.9	...	...	1.0	2.0	1095	High polished

built automatic machine, standardized and calibrated for metal losses so that plate thickness after buffing conformed closely to the intended value.[3]

The sequence of steps in the cleaning and plating cycles for plating nickel on steel, copper on steel, nickel on a copper flash, nickel on buffed or unbuffed copper, and bright nickel on buffed nickel are recorded in Table VII. In cases requiring a deposit of Watts or bright nickel over an unbuffed undercoat of copper or nickel, the first deposit was given a cold spray rinse, a cold dip rinse, and a cold spray rinse before applying the second deposit. The cleaning and plating cycles were carried out on racks holding eight of the 4 by 6 in. panels.

TABLE VI.—SOURCE AND COMPOSITION OF STEEL.

	S.A.E. 1095 Steel, Jessup Steel Co.	S.A.E. 9112 Steel, Great Lakes Steel Co.
Carbon, per cent	1.00	0.12
Manganese, per cent	0.78	0.64
Phosphorus, per cent	0.014	0.021
Sulfur, per cent	0.014	0.025
Silicon, per cent	0.36	0.88
Chromium, per cent	0.06	0.62
Zirconium, per cent	....	0.65

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[3] Details of buffing procedure are described by C. C. Cupps and A. Kenneth Graham, *Proceedings*, Am. Electroplaters Soc., pp. 276–280 (1947).

TABLE VII.—CLEANING AND PLATING CYCLES.

Step	Nickel on Steel	Copper on Steel or Nickel on Strike or Heavy Unbuffed Copper	Nickel on Buffed Copper	Bright Nickel on Buffed Nickel
No. 1	Cathodic clean	Cathodic clean	Anodic clean	Cathodic clean
No. 2	Hot rinse	Hot rinse	Hot rinse	Hot rinse
No. 3	Anodic clean	Anodic clean	Cold spray rinse	Cold spray rinse
No. 4	Hot rinse	Hot rinse	Cold dip rinse	Cold dip rinse
No. 5	Cold spray rinse	Cold spray rinse	NaCN dip	Anodic H_2SO_4
No. 6	Cold dip rinse	Cold dip rinse	Cold spray rinse	Cold dip rinse
No. 7	HCl dip	HCl dip	Cold dip rinse	Cold spray rinse
No. 8	Cold dip rinse	Cold dip rinse	H_2SO_4	Cathodic clean
No. 9	Cold spray rinse	Cold spray rinse	Cold dip rinse	Hot rinse
No. 10	Ni plate	Cyanide Cu strike	Cold spray rinse	Cold spray rinse
No. 11		Cold spray rinse	Cyanide Cu strike	HCl dip
No. 12		H_2SO_4 dip	Cold spray rinse	Cold dip rinse
No. 13		Cold spray rinse	H_2SO_4 dip	Cold spray rinse
No. 14		Cold dip rinse	Cold spray rinse	Ni plate
No. 15		Cold spray rinse	Cold dip rinse	
No 16		Acid Cu plate or Ni plate	Cold spray rinse	
No. 17			Ni plate	

The solution compositions and operating conditions used in the above cycles were as follows:

Cathodic Alkaline Cleaner (*Proprietary*), 10 oz. per gal., 200 F., 30 amp. per sq. ft., 2 min.

Anodic Alkaline Cleaner (*Proprietary*), 10 oz. per gal., 180 F., 75 amp. per sq. ft., 1.5 min.

HCl Dip, 50 per cent by volume (20°Baume), 70 to 80 F., on S.A.E. 1095 steel for 30 sec., on S.A.E. 9112 steel for 20 sec., and on buffed nickel prior to bright nickel, 90 F. for 3 min.

Anodic H_2SO_4, 30 per cent by weight 60 F., 15 amp. per sq. ft., 1 min.

H_2SO_4 Dip, 10 per cent by volume (66°Baume), 60 to 70 F., 30 sec. for buffed copper, 5 sec. after cyanide strike.

Watts Nickel

Nickel	12.9 oz. per gal.
$NiCl_2 \cdot 6H_2O$	5.2 oz. per gal.
$NiSO_4 \cdot 6H_2O$	52.2 oz. per gal.
H_3BO_3	3.8 oz. per gal.
Wetting agent	

pH 2.0 to 2.3, 120 F., 50 amp. per sq. ft., surface tension 36 dynes per cm.

Semibright Nickel (*Proprietary*)

Nickel	13.4 oz. per gal.
$NiCl_2 \cdot 6H_2O$	4.0 oz. per gal.
$NiSO_4 \cdot 6H_2O$	46.1 oz. per gal.
H_3BO_3	3.8 oz. per gal.
$Ni(HCOO)_2$	5.8 oz. per gal.
$CoSO_4 \cdot 6H_2O$	0.16 oz. per gal.
$(NH_4)_2SO_4$	0.10 oz. per gal.
HCHO	0.33 oz. per gal.

pH 2.3 to 2.5, 150 F., 50 amp. per sq. ft., air agitation.

Bright Nickel (*Proprietary*)

Nickel	13.9 oz. per gal.
$NiCl_2 \cdot 6H_2O$	10.0 oz. per gal.
$NiSO_4 \cdot 6H_2O$	51.3 oz. per gal.
H_3BO_3	5.2 oz. per gal.
Brightener organic addition agents	

pH 4.0 to 4.2, 140 F., 40 amp. per sq. ft., surface tension 35 dynes per cm.

Rochelle Copper Strike

Copper	2.4 oz. per gal.
CuCN	3.4 oz. per gal.
Free NaCN	0.6-0.8 oz. per gal.
Na_2CO_3	3.8 oz. per gal.
Rochelle salts	4.0 oz. per gal.

pH 12.2 to 12.4, 150 to 160 F., 30 amp. per sq. ft.

Acid Copper

Copper	9.8 oz. per gal.
$CuSO_4 \cdot 5H_2O$	38.8 oz. per gal.
H_2SO_4	6.2 oz. per gal.
Molasses	0.5 ml. per gal.

110 F., 30 amp. per sq. ft., air agitation.

All panels were given the usual final chromium plate from a bath containing 53 oz. per gal. of CrO_3 and 0.53 oz. per gal. of H_2SO_4. Prior to chromium plating, the buffed or bright nickel was given a cathodic clean (Na_2CO_3, 8 oz. per gal., Na_3PO_4, 1 oz. per gal., NaOH, 2 oz. per gal.) for 5 min. at 170 to 180 F. and at 25 to 30 amp. per sq. ft., followed by a cold spray rinse, an HCl dip (15 per cent by volume, 70 to 80 F. for 30 sec.), and a final cold spray rinse.

TABLE VIII.—CHARACTERISTICS OF PLATED PANELS.

Steel—	Final hardness (S.A.E. 1095) (Brinell)			Mean 330		Av. dev. ±5.6
	Profilometer, microinches			Av. r.m.s. 8.1		Av. dev. ±2.3
Copper—	Intended thickness, mils			0.5	1.0	1.5
	Actual, mils			0.4 to 0.7	0.9 to 1.1	1.4 to 1.5
Nickel—	Intended thickness, mils	0.5	1.0	1.5	2.0	3.0
	Actual, mils	0.5 to 0.6	0.9 to 1.1	1.3 to 1.5	1.8 to 2.0	2.8 to 3.0
Chromium—	Intended thickness, mils					0.010 to 0.020
	Actual, mils					0.011 to 0.023

Before using the plating solutions, recognized purification methods were utilized to insure representative deposits equal to good commercial practice.

Several panels from each lot were used for plate thickness and adherence tests. Table VIII summarizes the variations in thickness of the copper, nickel, and chromium plates from panel to panel on all lots. Plate variation over the surface of any one panel also falls within the limits shown. The table also contains a summary of the hardness data and profilometer readings made on the unplated steel panels. It can be seen that highly satisfactory conformance to intended plate characteristics has been achieved.

Distribution of Panels to Exposure Sites:

To minimize possible but unknown differences that might have been due to position on the plating rack or variations from rack to rack for a given lot, the panels were randomized into nine groups of five panels each. One of these randomized groups was then exposed to the atmosphere at each of the selected exposure sites on racks of the type previously used by the subcommittee. The racks hold the panels at an angle of 30 deg. from the horizontal, facing south, in five horizontal rows of 37 columns. The five specimens of a lot were mounted in a single vertical column.

Inspection Method:

To provide a means of recording inspection data, a system of rating numbers (from 10 to 0), based on the percentage defective area at any given exposure time, has been used. The rating number system is supplemented by an abbreviated description of the type of defect. In view of the uncertainties in estimating

TABLE IX.—ABBREVIATIONS DESCRIBING DEFECTS.

TYPES OF FAILURE

R = Corrosion (rusting) of the basis metal. (Permanent or massive type of basis metal corrosion such as that in pinholes, bare or flaked areas, or in craters of broken blisters.)
Rs = Stain due to basis metal corrosion products, such as rust stain, which can be removed readily with a damp cloth or chamois and mild abrasive revealing a sound bright surface.
S = Stains or spots other than that of *obvious* basis metal corrosion products.
Sp = Surface pits. Corrosion pits probably not extending through to the basis metal—that is, absence of *obvious* basis metal corrosion products bleeding therefrom.
F = Flaking or peeling of deposit.
B = Blistering.
C = Cracking.
Z = Crazing.
W = Crow's feet.

DEGREE OR EXTENT OF PINHOLE RUSTING, STAINING, SURFACE PITTING, FLAKING, ETC.

vs = very slight amount.
s = slight amount.
i = intermediate or moderate amount.
x = excessive amount.

DESCRIPTION OF BLISTERS

s = less than about 0.5 mm. in diameter.
i = about 0.5 to 2.0 mm. in diameter.
x = greater than about 2.0 mm. in diameter.
vf = 5 or fewer.
f = 5^+ to 25.
i = 10^+ to 25.
m = 25^+ to 50.
vm = over 50.

DESCRIPTION OF LOCATION OF DEFECTS

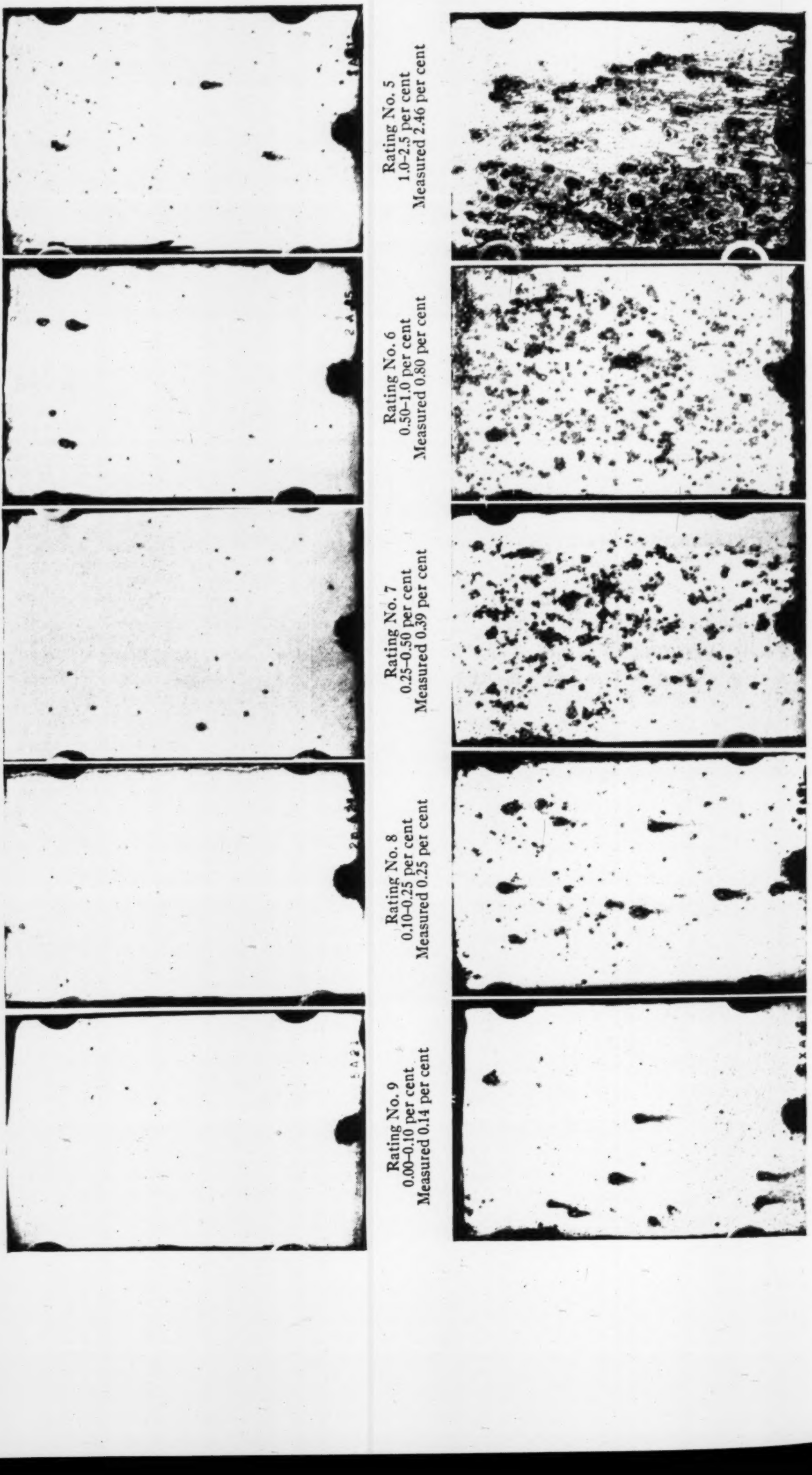
e = edge g = general

EXAMPLES

(1) ipR, vscR, sRs = a moderate amount of pin-point type rusting, a very slight amount of crater-type rusting, and a slight amount of rust stain of which can be readily removed.

(2) iSp, iS, iiW, seZ = moderate surface pitting, moderate staining (other than rust), an intermediate number of moderate sized crow's feet, a small amount of edge crazing.

(3) xcR, xRs = excessive crater-type rust spots and an excessive amount of removable rust over a sound, bright surface.



Rating No. 9
0.00–0.10 per cent
Measured 0.14 per cent

Rating No. 8
0.10–0.25 per cent
Measured 0.25 per cent

Rating No. 7
0.25–0.50 per cent
Measured 0.39 per cent

Rating No. 6
0.50–1.0 per cent
Measured 0.80 per cent

Rating No. 5
1.0–2.5 per cent
Measured 2.46 per cent

Rating No. 4
2.5–5.0 per cent
Measured 4.0 per cent

Rating No. 3
5–10 per cent
Measured 9.5 per cent

Rating No. 2
10–25 per cent
Measured 20.6 per cent

Rating No. 1
25–50 per cent
Measured 28.1 per cent

Rating No. 0
50–100 per cent
Measured 64.5 per cent

FIG. 4.—Photographic Standards.

TABLE X.—INSPECTION DATA (For key to symbols, see Table IX).
NEW YORK.

Lot	Steel (S.A.E.)	Coating, mils			0.10 yr.		0.57 yr.		0.96 yr.		1.22 yr.		1.46 yr.	
		Cu	Ni	Total	Rating	Description	Rating	Description	Rating	Description	Rating	Description	Rating	Description
No. 1	1095	...	1.0	1.0	10		4	vspR; iSp; iS	4	vspR; iSp	4	xpR; sRs; iSp	3	xpR; scR; sRs; iSp; sW
No. 2		0.1	0.9	1.0	10		4	“ “ “	4	“ “ ; fsB	4	“ “ “ ; iB	3	“ sRs; sSp; seZ; feB
No. 3		0.5	0.5	1.0	10		2	xpR; xRs	2	xpR; iRs	2	xcR; iRs	1	xcR; xRs; xSp; seZ
No. 4		0.5^{b}	0.5	1.0	10		2	“ “	2	“ “	2	“ “	1	“ “ “ “
No. 4NA		...	0.5^{b} +0.5	1.0	10		4	vspR; iSp; iS	4	spR; sRs	3	xpR; sRs	3	xpR; iRs; sSp; ieZ; sW
No. 4B		...	0.5^{ba} +0.5	1.0	10		5	“ “ “	5	vspR; iSp	5	spR; sRs; iSp	4	spR; sRs; iSp; iS
No. 5X		...	1.0 (*pH*)	1.0	10		4	“ “ “	4	spR; sRs	4	“ “ “	3	ipR; iRs; iSp; seZ
No. 6X		0.1	0.9 (*pH*)	1.0	10		4	“ “ “	4	“ “ ; fsB	4	“ “ “	3	“ “ “ fsB
No. 5	1095	...	1.5	1.5	10		4	“ “ “	4	vspR iSp	4	“ “ “	3	“ “ “ seZ
No. 6		0.1	1.4	1.5	10		5	“ “ “	4	“ “	5	vspR; iSp	4	spR; sRs; iSp; sS
No. 7		0.5	1.0	1.5	10		3	ipR; sRs; iS	3	ipR; sRs; iSp	3	ipR; iRs; iSp	2	ipR; scR; iRs; iSp
No. 8		1.0	0.5 (*WA*)	1.5	10		2	xpR; xRs	2	xpR; iRs; fsB	2	xpR; scR; sRs	1	xpR; icR; iRs; seZ; fiB
No. 9		1.0^{b}	0.5	1.5	10		2	“ “	2	“ “	2	“ “	1	“ scR; iRs; seZ; fsB
No. 9NA		...	1.0^{b} +0.5	1.5	10		4	vspR; iSp; iS	5	iSp	4	vspR; iSp	3	spR; sRs; iSp; seZ
No. 10	1095	...	2.0	2.0	10		5	iSp; iS	5	“	5	“ “	4	“ “ “ “
No. 11		0.1	1.9	2.0	10		5	“ “	5	“	6	“ “	4	“ “ “ “
No. 12		0.5	1.5	2.0	10		5	“ “ ; iZ	4	“	5	“ “	4	“ “ “ “ ; iC
No. 13		1.0	1.0	2.0	10		4	“ “ “	3	spR	3	ipR; iRs; iSp	2	ipR; iRs; iSp; iS; sC
No. 14		1.0^{b}	1.0	2.0	10		4	“ “	3	“	3	“ “ “	2	“ “ “ “ eZ
No. 14NA		...	1.0^{b} +1.0	2.0	10		5	“ “	5	iSp	6	vspR; iSp	4	spR; vsRs; iSp; sW
No. 14B		...	1.0^{ba} +1.0	2.0	10		5	“ “	5	“	6	“ “	4	“ “ “ “
No. 15		1.5	0.5	2.0	10		2	spR; sRs; iSp; iS	2	ipR; iRs	2	xpR; xRs; iSp	1	xpR; xRs; iSp; iS; xeZ
No. 16		1.5^{b}	0.5	2.0	10		2	“ “ “ “	2	“ “	2	“ “ “	1	“ “ “ “ “
No. 10X	1095	...	3.0	3.0	10		5	iSp; iS	5	iSp	6	iSp	4	iSp
No. 14X		1.0	2.0	3.0	10		5	“ “	5	“	6	“	4	“
No. 16X		1.5	1.5	3.0	10		4	“ “	4	“	4	vspR; iSp	3	spR; sRs; iSp; iS
No. 25	9112	...	1.5	1.5	10		4	vspR; iSp; iS	4	ipR; sRs; iSp	4	ipR; sRs; iSp	3	ipR, sRs; iSp; seZ
No. 26		0.1	1.4	1.5	10		4	“ “ “	4	vspR; iSp	6	vspR; iSp	3	“ “ “ “
No. 27		0.5	1.0	1.5	10		3	ipR; sRs; iSp	3	ipR; sRs; **iSp**	3	spR; iRs; iSp; iC	2	xSp
No. 28	1095	...	2.0SB	2.0	10		4	vspR; iSp; iS	4	vspR; iSp; fsB; eF	5	“ iSp; fsB; seF	4	spR; sRs; iSp; iS; ieF
No. 29		1.0	1.0SB	2.0	10		3	ipR; sRs; iSp	2	ipR; sRs; iSp	3	“ iRs; iSp; ieC	2	ipR; sRs; iSp; iS; ieZ
No. 29NA		...	1.0^{b} +1.0SB	2.0	10		3	iSp; iS; iY	4	vspR; iSp	4	vspR; xSp; seC	3	spR; vsRs; sXp; seZ
No. 30	1095	1.0	1.0B	2.0	10		3	ipR; iRs; iSp	3	ipR; iRs; iSp	4	ipR; sRs; iSp	2	ipR; sRs; iSp; fiB
No. 31		1.0^{b}	1.0B	2.0	10		3	“ “ “	3	“ “ “	2	xpR; xRs; iSp	2	“ scR; iRs; iSp; xS
No. 32		0.1	0.9 +1.0B	2.0	10		4	iSp	4	iSp	5	iSp	4	spR; sRs; iSp; ixW
No. 33		0.1	0.9^{b} +1.0B	2.0	10		4	“	4	“	5	“	4	“ “ “ “
No. 34	1095 high-polish	0.1^{b}	0.9^{b} +1.0B	2.0	10		3	“	3	“	2	xSp	3	xSp

(Continued on page 234 to 237.)

KURE BEACH.

Lot	Steel (S.A.E.)	Coating, Mils			0.13 yr.		0.62 yr.		1.17 yr.	
		Cu	Ni	Total	Rating	Description	Rating	Description	Rating	Description
No. 1	1095	...	1.0	1.0	9	vspR	8	spR	5	ipR; icR; iRs
No. 2		0.1	0.9	1.0	10		8	vspR	5	“ “ “
No. 3		0.5	0.5	1.0	5	ipR	1	xcR; sRs	0	xpR; xcR; xRs
No. 4		0.5^b	0.5	1.0	8	spR	1	“ “	0	“ “ “
No. 4NA		...	0.5^b +0.5	1.0	10		10		9	vspR
. 4B		...	0.5^b +0.5	1.0	10		9	vspR	9	spR; vsRs
No. 5X		...	1.0 (*pH*)	1.0	10		9	“	7	ipR; icR; iRs
No. 6X		0.1	0.9 (*pH*)	1.0	10		8	“	4	“ “ “
No. 5	1095	...	1.5	1.5	10		9	“	8	spR; vscR; sRs
No. 6		0.1	1.4	1.5	10		9	“	8	“ sRs
No. 7		0.5	1.0	1.5	9	vspR	6	ipR	4	ipR; icR; iRs
No. 8		1.0	0.5 (*WA*)	1.5	9	spR	5	“ ; xcR	3	“ ; xcR; iRs
No. 9		1.0^b	0.5	1.5	9	vspR	5	“ “	3	“ “ “
No. 9NA		...	1.0^b +0.5	1.5	10		9	vspR	9	vspR
No. 10	1095	...	2.0	2.0	10		9	“	9	spR; vsRs
No. 11		0.1	1.9	2.0	10		9	“	9	vspR; vsRs
No. 12		0.5	1.5	2.0	10		9	“	8	spR; sRs
No. 13		1.0	1.0	2.0	10		8	“	7	ipR; scR; vsRs
No. 14		1.0^b	1.0	2.0	10		9	“	6	ipR; scR; sRs
No. 14NA		...	1.0^b +1.0	2.0	10		9	“	9	vspR; vsRs
No. 14B		...	1.0^{ba} +1.0	2.0	10		9	“	9	vspR
No. 15		1.5	0.5	2.0	7	spR	4	xpR	2	ipR; xcR; xRs
No. 16		1.5^b	0.5	2.0	8	vspR	5	“	5	spR; xcR; xRs
No. 10X	1095	...	3.0	3.0	10		9	vspR	9	vspR
No. 14X		1.0	2.0	3.0	10		10		9	“
No. 16X		1.5	1.5	3.0	10		10		9	“
No. 25	9112	...	1.5	1.5	10		9	vspR	8	spR; vscR; sRs
No. 26		0.1	1.4	1.5	10		9	“	9	“ “ “
No. 27		0.5	1.0	1.5	9	vspR	6	ipR	3	ipR; xcR; xRs
No. 28	1095	...	2.0SB	2.0	10		8	vspR	7	ipR; iRs; ef
No. 29		1.0	1.0SB	2.0	10		7	spR	7	“ “ “
No. 29NA		...	1.0^b +1.0SB	2.0	10		9	vspR	7	spR; scR; iRs
No. 30	1095	1.0	1.0B	2.0	9	vspR	6	ipR	6	spR; icR; iRs; iSp
No. 31		1.0^b	1.0B	2.0	10		7	“	8	“ iSp
No. 32		0.1	0.9 +1.0B	2.0	10		9	vspR	9	“ “
No. 33		0.1	0.9^b +1.0B	2.0	10		10		9	vspR; iSp
No. 34	1095 high polish	0.1^b	0.9^b +1.0B	2.0	10		10		9	iSp

STATE COLLEGE.

Lot	Steel (S.A.E.)	Coating, Mils			0.13 yr.		0.58 yr.		1.17 yr.		1.47 yr.	
		Cu	Ni	Total	Rating	De-scrip-tion	Rating	Description	Rating	Description	Rating	Description
No. 1	1095	...	1.0	1.0	10		9	vspR	8	spR	8	ipR; vsRs
No. 2		0.1	0.9	1.0	10		9	“	10		9	vspR
No. 3		0.5	0.5	1.0	10		8	“	9	vspR; vseZ; vivsB	6	ipR; sRs; msB; seZ
No. 4		0.5^b	0.5	1.0	10		9	“	9	“ ; vivsB	8	spR; sS; msB
No. 4NA		...	0.5^b +0.5	1.	10		10		10	vseZ	9	vspR
No. 4B		...	0.5^b +0.5	1.0	10		10		10		10	
No. 5X		...	1.0 (*pII*)	1.0	10		9	vspR	9	vspR	9	spR
No. 6X		0.1	0.9 (*pII*)	1.0	10		9	“	9	“	9	vspR; fsB
No. 5	1095	...	1.5	1.5	10		9	“	9	“	9	vspR
No. 6		0.1	1.4	1.5	10		10		10		10	
No. 7		0.5	1.0	1.5	10		10		10		10	
No. 8		1.0	0.5 (*WA*)	1.5	10		7	vsS	9	vspR; seF	7	vspR; vsRs; sS; vseF
No. 9		1.0^b	0.5	1.5	10		8	“	9	“	7	“ “ “
No. 9NA		...	1.0^b +0.5	1.5	10		10		10		10	seZ
No. 10	1095	...	2.0	2.0	10		10		10		10	
No. 11		0.1	1.9	2.0	10		10		10		10	
No. 12		0.5	1.5	2.0	10		9	vspR; sZ	10		10	
No. 13		1.0	1.0	2.0	10		10		10		9	sS
No. 14		1.0^b	1.0	2.0	10		10		10		9	sS
No. 14NA		...	1.0^b +1.0	2.0	10		10		10		10	seZ
No. 14B		...	1.0^{ba} +1.0	2.0	10		10		10		10	
No. 15		1.5	0.5	2.0	10		10		10		8	sSp; sS
No. 16		1.5^b	0.5	2.0	10		10		10		9	vsSp; vsS
No. 10X	1095	...	3.0	3.0	10		10		10		10	
No. 14X		1.0	2.0	3.0	10		10		10		10	
No. 16X		1.5	1.5	3.0	10		10		10		10	
No. 25	9112	...	1.5	1.5	10		9	vsS; sZ	9	vspR	9	vspR
No. 26		0.1	1.4	1.5	10		10		10		10	
No. 27		0.5	1.0	1.5	10		9	vsS	10	seZ	9	vsS
No. 28	1095	...	2.0SB	2 0	10		10		9	seB	8	sF
No. 29		1.0	1.0SB	2.0	10		8	vsS	10		9	sSp
No. 29NA		...	1.0^b +1.0SB	2.0	10		10		10		10	vseF
No. 30	1095	1.0	1.0B	2.0	10		10		10		8	SpR; sS
No. 31		1.0^b	1.0B	2.0	10		10		10		9	vspR; sS; seZ
No. 32		0.1	0.9 +1.0B	2.0	10		10		10		8	sSp; vseZ; ivsW
No. 33		0.1	0.9^b +1.0B	2.0	10		10		10		8	“ “ “
No. 34	1095 high-polish	0.1^b	0.9^b +1.0B	2.0	10		10		10		9	vsS

PITTSBURGH.

Lot	Steel (S.A.E.)	Coating, Mils			0.12 yr.		0.57 yr.		0.95 yr.		1.16 yr.		1.47 yr.	
		Cu	Ni	Total	Rating	Description	Rating	Description	Rating	Description	Rating	Description	Rating	Description
No. 1	1095	...	1.0	1.0	9	vspR	0	xpR; iRs; iSp	1	xpR; iRs	2	xpR; xRs; eZ	0	xpR; xRs; fiB; ieZ
No. 2		0.1	0.9	1.0	10		2	“ “ “	1	“ “	2	“ “ “	0	xpR; xRs; miB; ieZ
No. 3		0.5	0.5	1.0	8	spR	0	xpR	0	xpR	0	xpR; xRs	0	xpR; xcR; xRs
No. 4		0.5^b	0.5	1.0	7	spR	0	“	0	“	0	“ “	0	“ “ “
No. 4NA		...	0.5^b +0.5	1.0	10		1	xpR; iRs; iSp	1	xpR; iRs	2	xpR; iRs; iZ	0	xpR; xRs; xC
No. 4B		...	0.5^{ba} +0.5	1.0	10		0	“ “ “	1	“ “	3	ipR; iRs; Sp; seZ	0	spR; xRs; xSp; xS; seZ
No. 5X		...	1.0 (*pH*)	1.0	10		0	xpR	1	“ “	2	ipR; Rs; iSp	0	xpR; xRs; seZ
No. 6X		0.1	0.9 (*pH*)	1.0	10		2	xpR; iRs; iSp	1	“ “	2	xpR; xRs; fsB	0	xpR; xRs; iiB; seZ
No. 5	1095	...	1.5	1.5	10		2	xpR; iRs; iSp	1	xpR; iRs	3	ipR; iRs; iSp	1	xpR; xRs; seZ
No. 6		0.1	1.4	1.5	10		3	xSp; iS	1	xpR; sRs	3	“ “ “	2	“ “ “
No. 7		0.5	1.0	1.5	10		2	xpR; iRs; iSp	0	xpR	0	xpR; xRs; seZ	0	xpR; xcR; xRs; ieZ
No. 8		1.0	0.5 (*WA*)	1.5	7	spR	0	spR	0	xpR; icR	0	xpR; scR; xRs	0	“ “ “ “
No. 9		1.0^b	0.5	1.5	7	spR	0	“	0	“ “	0	“ “ “	0	“ “ “ “
No. 9NA		...	1.0^b +0.5	1.5	10		4	spR; iSp; iS	1	xpR; iRs	3	ipR; sRs; sSp; eZ	0	xpR; xRs; ieZ
No. 10	1095	...	2.0	2.0	10		5	xSp; iS	2	spR; sRs; iS	4	spR; sRs; iSp; sez	3	ipR; sRs; iSp; iS; seZ
No. 11		0.1	1.9	2.0	10		5	“ “	4	iSp; iS	4	iSp	3	spR; “ “ “ “
No. 12		0.5	1.5	2.0	10		4	xSp; iS; sZ	4	“ “	4	iSp; eZ	3	iSp; iS; iZ
No. 13		1.0	1.0	2.0	10		3	xSp; iS	2	spR; iS	2	ipR; iRs; iSp; iS; xZ	0	spR; xRs; iSp; xS; xC
No. 14		1.0^b	1.0	2.0	10		3	ipR; xSp; iS	0	xpR	0	xpR; iRs; iS; eZ	0	“ “ “ “ iiB
No. 14NA		...	1.0^b +1.0	2.0	10		5	xSp; iS	3	spR; xSp; iS	4	spR; sRs; iSp; eZ	1	spR; sRs; xSp; xS; seZ
No. 14B		...	1.0^{ba} +1.0	2.0	10		5	“ “	4	“ “ “	4	spR; iSp; eZ	1	“ “ “ “ ieZ
No. 15		1.5	0.5	2.0	8	spR	0	zpR	0	xpR	0	xpR; icR; iRs; iS	0	xpR; xcR; xRs
No. 16		1.5^b	0.5	2.0	8	spR	0	“	0	“	0	“ “ “ “	0	“ “ “
No. 10X	1095	...	3.0	3.0	10		4	xSp; iS	4	vspR; iSp	4	uspR; iSp	3	vspR; iSp; iS; seZ
No. 14X		1.0	2.0	3.0	10		5	“ “	4	iSp	4	“ “	3	“ “ “ “
No. 16X		1.5	1.5	3.0	10		5	“ “	3	ipR; iSp; sS	3	ipR; sRs; iSp	1	xpR; xRs; iSp; iS; seZ
No. 25	9112	...	1.5	1.5	10		2	ipR; iSp	1	xpR; iRs	2	spR; iRs; iSp; iZ	0	xpR; scR; xRs; iS; ieZ
No. 26		0.1	1.4	1.5	10		3	“ “	1	“ “	2	spR; iRs; iSp; seZ	0	xpR; scR; xRs; iS; fiB
No. 27		0.5	1.0	1.5	10		0	xpR	0	xpR	0	xpR; xRs	0	xpR; scR; xRs; iZ
No. 28	1095	...	2.0SB	2.0	10		5	spR; xSp; iS	2	ipR; fsB	4	spR; sSp; seF; sW	2	xpR; iRs; iSp; xeF; sF
No. 29		1.0	1.0SB	2.0	10		0	xpR	0	xpR	0	xpR; xRs; iS; xel	0	xpR; xRs; scR; ieZ
No. 29NA		...	1.0^b +1.0SB	2.0	10		1	ipR; xSp; iS	0	“	3	spR; iRs; iSp; eZ	0	xpR; xRs; seZ; sF
No. 30	1095	1.0	1.0B	2.0	9	vspR	1	ipR; xSp; iS	0	xpR	1	xpR; xRs; iS	0	xpR; icR; xRs
No. 31		1.0^b	1.0B	2.0	9	spR	0	xpR	0	“	0	“ “ “	0	“ “ “
No. 32		0.1	0.9 +1.0B	2.0	10		2	ipR; XSp	3	spR; xSp	4	ipR; sSp; W	2	xpR; sRs; xSp; xS; iiW; seZ
No. 33		0.1	0.9^b +1.0B	2.0	10		3	xSp; iS	3	“ “	4		2	spR; sRs; xSp; xSi; ixW; seZ
No. 34	1095	0.1^b	0.9	2.0	10		0	xSp; xS	2	xSp; iS	4		0	spR; sRs; xSp; xS; vsef

DETROIT (ATMOSPHERIC PLUS PERIODIC SALT SOLUTION).

DETROIT (ATMOSPHERIC PLUS PERIODIC SALT SOLUTION).

Lot	Steel (S.A.E.)	Coating, Mils			0.58 yr.		0.95 yr.		1.17 yr.	
		Cu	Ni	Total	Rating	Description	Rating	Description	Rating	Description
No. 1	1095	...	1.0	1.0	2	xpR; iRs	2	xpR; iRs	2	spR; seZ
No. 2		0.1	0.9	1.0	2	xpR; iRs; fsB	2	“ “	2	xpR; scR; sRs; ieZ
No. 3		0.5	0.5	1.0	0	“	0	xcR	0	“ xcR; xRs
No. 4		0.5^b	0.5	1.0	0	“	0	“	0	“ “ “ ; eZ
No. 4NA		...	0.5^b +0.5	1.0	.		.		.	
No. 4B		...	0.5^b +0.5	1.0	.		.		.	
No. 5X		...	1.0 (*p/l*)	1.0	1	xpR; fsB	1	xpR; icR	1	xpR; sRs; vmiB; seZ
No. 6X		0.1	0.9 (*p/l*)	1.0	1	“ “	1	“ “	1	“ xcR; miB; seZ
No. 5	1095	...	1.5	1.5	3	spR; iSp	2	xpR; iRs	2	xpR; sRs; seZ
No. 6		0.1	1.4	1.5	3	“ “	3	“ sRs; iSp	2	ipR; iSp
No. 7		0.5	1.0	1.5	2	xpR; iSp	0	“ xcR; xRs	0	xpR; scR; xRs
No. 8		1.0	0.5 (*WA*)	1.5	0	xpR; xB	0	xcR	0	“ xcR; xRs; seF
No. 9		1.0^b	0.5	1.5	0	“ “	0	“	0	“ scR; xRs
No. 9NA		...	1.0^b +0.5	1.5	.		.		.	
No. 10	1095	...	2.0	2.0	3	xSp; iS	3	xSp; sS	2	vspR; xSp; seZ
No. 11		0.1	1.9	2.0	3	“ “	3	“ “	2	xSp; seZ
No. 12		0.5	1.5	2.0	3	vspR; xSp; iS	3	spR; sXp; sS	2	vspR; xSp; ieZ
No. 13		1.0	1.0	2.0	2	spR; xSp; iS	2	ipR; sRs; iSp	2	ipR; iSp; sZ
No. 14		1.0^b	1.0	2.0	2	ipR; xSp; iS	0	xpR	0	xpR; scR; xRs; miB
No. 14NA		...	1.0^b +1.0	2.0	.		.		.	
No. 14B		...	1.0^{ba} +1.0	2.0	.		.		.	
No. 15		1.5	0.5	2.0	0	xpR	0	xcR	0	xpR; xcR; xRs
No. 16		1.5^b	0.5	2.0	0	“	0	“	0	“ “ “ ; seZ
No. 10X	1095	...	3.0	3.0	3	xSp; iS	3	xSp; sS	2	xSp
No. 14X		1.0	2.0	3.0	4	iSp; iS	5	iSp; vsS	5	vspR; iSp
No. 16X		1.5	1.5	3.0	2	ipR; iSp; iS	2	xpR; iRs	1	xpR; sRs; iSp; sS
No. 25	9112	...	1.5	1.5	2	spR; iSp; iS	3	spR; xSp; iS	1	spR; sRs; xSp; xS; xZ
No. 26		0.1	1.4	1.5	2	“ “ “	3	“ “ “	2	“ “ “ “ seZ
No. 27		0.5	1.0	1.5	0	xpR	0	xpR; icR	0	xpR; icR; xRs; ieZ
No. 28	1095	...	2.0SB	2.0	3	xSp; iS	3	xSp; sS	3	spR; xSp; ieF
No. 29		1.0	1.0SB	2.0	2	ipR; iSp	0	xpR; icR	0	xpR; xcR; xRs; ieZ
No. 29NA		...	1.0^b +1.0SB	2.0	.		.		.	
No. 30	1095	1.0	1.0B	2.0	2	xpR	0	xcR	0	xpR; xcR; xRs
No. 31		1.0^b	1.0B	2.0	2	“	0	“	0	“ “ “ ; seZ
No. 32		0.1	0.9 +1.0B	2.0	3	xSp; iS	3	xSp; sS	2	spR; xSp; fsB
No. 33		0.1	0.9^b +1.0B	2.0	3	“ “	3	“ “	3	“ “ “
No. 34	1095 high-polish	0.1^b	0.9^b +1.0B	2.0	2	xSp; xS	3	spR; xSp; sS	1	spR; xSp

accurately the per cent of panel area defective, a set of photographic standards has been adopted. The per cent of the total panel area that has deteriorated with respect to appearance has been carefully measured on the original photographic prints. The standards are reproduced as Fig. 4, which shows the actual per cent defective area, the rating number, and the range of defective area defined by each rating number. It should be noted that the rating number is a logarithmic function of the per cent defective area and that a rating number of 10 necessitates that the panel be perfect.

The system of abbreviations used to supplement the rating number record and to define the type of deteriorations is given in Table IX.

The subcommittee feels that the use of this combined system reduces the element of personal opinion on the part of inspecting groups, permits a fairly accurate visualization of the condition of a coating from written records, and yields data that are susceptible to graphical analysis.

Test Results:

The inspection data available to date are summarized in Table X. Some discrepancies occur in rating numbers which indicate that differences of one or two units are not significant.

The tests are being continued and a detailed analysis of the data and a complete statement of the conclusions will be included in a subsequent report.

Respectfully submitted on behalf of the subcommittee,

H. A. Pray,
Chairman.

REPORT OF COMMITTEE B-9
ON
METAL POWDERS AND METAL POWDER PRODUCTS*

This report covers the activities of Committee B-9 on Metal Powders and Metal Powder Products for the period from June, 1948, to June, 1949. During this time one meeting was held, in Pittsburgh, Pa., on February 1, 1949.

The committee notes with sorrow the death, during the past year, of C. W. Balke of the Fansteel Metallurgical Corp. Dr. Balke was a charter member of Committee B-9 and contributed greatly to the work of the committee.

NEW TENTATIVE

The committee recommends for publication as tentative the Definitions of Terms Relating to Powder Metallurgy, as appended hereto.[1]

TENTATIVE CONTINUED WITHOUT REVISION

The committee recommends that the Tentative Specifications for Sintered Metal Powder Structural Parts (B 222 – 47 T)[2] be retained as tentative without revision.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Nomenclature and Technical Data (F. N. Rhines, chairman).—During the past year, this subcommittee reviewed the glossary of definitions of terms relating to powder metallurgy which had previously been approved by main committee ballot and submitted to Committee E-8 on Nomenclature and Definitions for comment. The comments of Committee E-8 were carefully considered and certain changes were incorporated in the glossary prior to its resubmission to main committee vote. It has now been approved as noted above and is submitted herewith for publication as a tentative.

Work on a standard tension test bar for use in testing metal powder materials received considerable attention. This work is now almost complete and the subsection is contacting interested individuals in the powder metallurgy industry for their comments prior to its submission as a standard test bar.

Subcommittee II on Metal Powders (D. O. Noel, chairman) has been considering three phases of work connected with the testing of metal powders. The first of these is the development of a standard test for the compressibility of metal powders. A test program in which nine laboratories cooperated indicated that this test is one which must be made under controlled conditions of die lubrication and surface finish. A paper summarizing the results of the

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[*] Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] These definitions were accepted as tentative by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 2.

[2] 1947 Supplement to Book of A.S.T.M. Standards, Part I-B.

[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

program is being written for publication in the ASTM BULLETIN.

A second phase of work in progress is the development of test methods for the chemical analysis of metal powders. This work has been carried on in cooperation with Committee E-3 on Methods of Chemical Analysis and with the Metal Powder Association. Particular emphasis is being placed on methods for the determination of insoluble matter in iron and copper and of the "hydrogen loss" of certain powders.

The third phase of work under consideration by Subcommittee II is that of subsieve particle size analysis. Task groups to investigate the applicability of currently used methods have been established and they will make recommendations.

Subcommittee III on Metal Powder Products (R. P. Koehring, chairman).—Section A on Bearings (D. S. Urquhart, chairman) had as its principal activity during the year a proposed revision of the Tentative Specifications for Metal Powder Sintered Bearings (B 202 - 45 T)[4] particularly with respect to chemical analysis and density ranges. These changes have been approved by the subcommittee and will be submitted to the main committee for ballot in the near future. In addition this section has had under consideration standard lists for recommended press fits of metal powder bearings and standard size lists for certain types of bearings. These lists when complete will be recommended for appending to the sintered bearing specification (B 202 - 45 T).

Section B on Structural Parts (F. V. Lenel, chairman).—Consideration was given to additional specifications in the structural parts field to cover materials of compositions other than those specified in Tentative Specifications B 222. It was considered that iron-carbon and iron-copper-carbon mixtures should be investigated as well as iron-copper mixtures of higher density than those covered in Specifications B 222. Task groups have been set up to investigate the desirability of recommending specifications covering these materials. In addition Section III-B has appointed task groups to determine the desirability of standard specifications for brass and bronze structural parts and for iron parts used in magnetic applications.

Section C on Sintered Carbides (J. C. Redmond, chairman) discussed the possibility of establishing standard test methods for determining the properties of cemented carbides and set up task groups to recommend procedures for measuring hardness, transverse bend strength, microstructure, and for preparing a chart giving comparative grades of carbides.

Section D on Friction Materials (F. White, chairman) had its first meeting during the year and determined that there was probably sufficient standardization in the friction-facing field to warrant an attempt to set up certain test methods and specifications for this material. Additional producer-consumer representation on this section will be cultivated.

This report has been submitted to letter ballot of the committee, which consists of 51 members; 39 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

W. A. REICH,
Chairman.

A. SQUIRE,
Secretary.

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[4] 1946 Book of A.S.T.M. Standards, Part I-B.

REPORT OF JOINT COMMITTEE
ON
EFFECT OF TEMPERATURE ON THE PROPERTIES OF METALS*

The ASTM-ASME Joint Committee on the Effect of Temperature on the Properties of Metals has held two meetings during the year: on December 2, 1948, during the Annual Meeting of The American Society of Mechanical Engineers in New York, N. Y., and on June 30, 1949, during the Annual Meeting of the A.S.T.M. In both instances the meetings were preceded by a meeting of the Technical Advisory Committee.

The membership of the main committee now consists of 25 members, not counting a representative of the National Bureau of Standards and a representative of the Bureau of Ships, Navy Department. The Executive Committee of five includes the officers of the main committee and two elected members. The Technical Advisory Committee comprises the Executive Committee and the six panel chairmen. (Currently two panel chairmen are also members of the Executive Committee, making nine members of the Technical Advisory Committee at present.)

Membership of the several panels as they stand at present is as follows:

Gas Turbine Panel	21
Aviation Panel	22
Steam Power Panel	26
Chemical and Petroleum Panel	29
General Research Panel	13
Data and Publications Panel	14

In conjunction with the December meeting, the committee sponsored a technical session at which two papers were presented:

"Cyclic Heating Test of Main Steam Piping Joints Between Ferritic and Austenitic Steel at Sewaren Generating Station," by H. Weisberg.

"Report on Graphitization Studies on High Temperature Welded Piping of the Philadelphia Electric Co.," by J. B. Abele and A. E. White.

At the meeting in June, reports were received from the Panel Chairmen as well as from the Chairmen of Current Research Projects:

Project No. 18 on Effect of Manufacturing Variables on the Creep Properties of Steel (H. C. Cross, chairman).—A report of this project appears in Appendix I.

Project No. 29 on Stability of Steels as Affected by Temperature (J. J. Kanter, chairman).—A report on this project appears in Appendix II.

Reports of the Panels are given below:

Gas Turbine Panel (C. T. Evans, Jr., chairman):

There has been considerable discussion in the Panel of a list of alloys, currently of interest to gas turbines other than aircraft, which it is intended to submit to the Data and Publications Committee with recommendation that the data on these compositions be assembled and correlated as soon as possible. However, the committee will be busy for at least six months in compiling data on ferritic steels and the 18-8 types of steel short of super alloys. Accordingly, the Gas Turbine Panel will rework the list thus far prepared and will attempt to have this ready for the Publications Committee by the end of this year.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

Activity under the various projects set up by the Gas Turbine Panel is as follows:

GTP1 on Fatigue.—I. R. Kramer (chairman), Messrs. Matters and Schabtach. Various phases of fatigue needing further study have been discussed. The influence of stress concentration is considered important and amenable to early study. The project was directed to organize a definite program and get it under way as promptly as possible.

GTP2 on Corrosion-Erosion.—C. T. Evans (chairman). Work to date shows that SO_2 appears to be innocuous to S-590, S-588 or 25-12 cast material (columbium). On the other hand, H_2S had a definite effect on 25-12 plus columbium in a short test at 1350 F. Coal ash coated or in loose contact had no effect on the stress rupture properties of S-588 alloy at 1350 F. No visible effects of corrosion have been discovered. Oil ash, however, containing approximately 10 per cent V_2O_5 and resulting from burning a residual from domestic crude oil had an effect on stress-rupture and visible corrosion on S-588 alloy at 1350 F. Alloy 19-9DL, however, shows negligible effects at this temperature on tests through at least 600 hr. Stress-free tests are under way with a wide variety of materials in contact with various ashes at 1000 F., 1350 F., and 1500 F.

Mr. Skinner of the International Nickel Co. has reported stress rupture tests on Inconel "X" at 1350 and 1500 F. using SO_2 contaminated gas. There is no apparent loss of strength.

It has been recommended that the Joint Committee sponsor a symposium on this subject for the June, 1950, ASTM meeting.

GTP3 on Test Methods.—J. W. Freeman (chairman), Messrs. Bash and Fleischmann. This group hopes to have a draft of a recommended practice for stress rupture testing ready for presentation to the main committee by December, 1949.

GTP4 on Statistical Variations.—G. Mohling (chairman), Thompson. Mr. Mohling has submitted a large amount of stress rupture data on S-816 alloy. Mr. Thompson is working with the statistical group at the National Bureau of Standards in an attempt to evaluate this information statistically.

GTP5 on Thermal Shock.—W. C. Stewart (chairman), Badger. A bibliography of work which had been done in this field and work in progress has been assembled which will be circulated to the panel with the request that each panel member advise the chairman of other work of which he has knowledge and work which he would like to have accomplished in this field.

Aviation Panel (L. Schapiro, chairman):

The Aviation Panel has had two subcommittees studying the possibilities of establishing research or testing programs on the items of importance to this industry. The following statements constitute the nearly unanimous recommendation by the Aviation Panel.

It is feasible to initiate a testing program at this time on the item voted most important to this industry with regard to sheet materials. This project, designated AP1A, constitutes the first phase of a study of sheet materials and has as its purpose "the statistical evaluation of the creep-rupture properties of five selected alloys by a study of ten lots of each alloy, with five sources of supply where the grade permits." The establishment of minimum engineering values from this test program will be very useful to the aviation industry. It is desired that Subcommittee 1 of this Panel direct this study which will constitute constant load to rupture testing 450 specimens and reporting the full deflection curve for each. This Panel expects through its membership to be able to acquire some of the material for this study and likewise to perform some of the test work. Expecting that it may not be able to perform the complete task without financial assistance, it requests the Joint Committee to approve this project "in principle" and will endeavor to submit in the next few months a more detailed statement of the extent of financial support that may be necessary.

The Panel finds that it is not feasible to initiate any testing program at this time pertaining to the important problems facing this industry in regard to blading materials. This condition results from a need within the industry to give further expression to its problems.

Steam Power Panel (N. L. Mochel, chairman):

The Panel held one meeting during the past year, with a second meeting planned for the fall of 1949. The Panel consists of 26 members, representing a wide variety of interests in the steam power fields, as follows:

Power Plants	6
Contractors and Engineers	1
Shipbuilders	1
U. S. Navy	1
Research Groups	2
Alloy and Steel Producers	5
Piping Contractor	1
Valves and Fittings	3
Boiler Makers	3
Turbine Builders	3

The Panel has critically reviewed all known research and development projects dealing with materials and materials applications of direct interest to the steam power field.

The Panel also reviewed requests for data and information that have come to it from various sources. The immediate demands for information on materials are in connection with new stations, some in operation, others building, in which steam temperatures have now reached the 1000 F. and 1050 F. levels. Austenitic steels have now been employed for pressure-carrying parts at this higher temperature.

The Panel has noted that the Panel on Data and Publications is recommending prompt publication of a collection of high-temperature test data, made available by one of its members, and it is believed that these data will serve as an excellent starting point for the Steam Power Panel to initiate further research and development to meet its long-time needs.

Chemical and Petroleum Panel (C. L. Clark, chairman):

The following projects have been agreed upon for the activities of this group:

Project	Title	Chairman
No. 1	Compilation of Experiences with Metals above 1500 F.	H. W. Schmidt
No. 2	Compilation of Experiences with Metals in Their Transition Temperature Range.	
No. 3	Relative Merits of 18-8 Stainless Steel *versus* the Stabilized Grades of Austenitic Steels.	M. S. Northup
No. 4	Necessity of Preheating and Stress-Relieving Ferritic Steels Welded with Austenitic Steels.	W. L. Bowler
No. 5	The Cracking at the Welds of 12 per cent Chromiun Type Liners in Pressure Vessels.	M. W. Barnes
No. 6	Differences in Graphitization in the Steam Power as Compared to the Petroleum and Chemical Industries.	W. B. Hoyt
No. 7	Experiences with Corrosion by Vanadium Compounds.	E. F. Tibbetts

Mr. G. A. Nelson, Shell Development Co., San Francisco, Calif., has been appointed Secretary of this panel.

General Research Panel (Alvin J. Herzig, chairman):

The General Research Panel is confining its initial effort to two programs: (1) The effect of the sigma phase on the properties of metals at elevated temperatures, and (2) the effect of temperature on the flow and fracture of metals.

A specific project has been outlined for the first program, and six specific subjects under the second program have been assigned to task groups.

On the recommendation of the task groups, action has been approved by the General Research Panel as follows:

Task Group No. 1, working on the subject of the sigma phase, found that at least twelve laboratories were already engaged in projects which would duplicate the proposed investigation. It was proposed and the Panel agreed that these laboratories be invited to participate in a symposium on the Effect of the Sigma Phase on the Properties of Metals at Elevated Temperatures. It is believed that a program of subjects can be completed for examination by the Panel at its December meeting and presentation at the June 1950 meeting of the A.S.T.M.

Task Groups Nos. 2 and 3 studied six subjects proposed by A. Nadai and Westinghouse Research Laboratories, under the general subject of "The Effect of Temperature on the Flow and Fracture of Metals." These subjects were:

1. An investigation of the conditions causing the occurrence of an inflection point in the standard creep curve of the long-time creep test.
2. Correlation of long-time constant-load creep test and the relaxation test.
3. The influence of the surrounding atmosphere or of certain gases, including combustion products in gas turbines on the creep of metals and on the fracture at high temperatures.
4. The effect of sharp notches on the fracture strength at high temperatures.
5. Study of creep and fracture conditions under biaxial states of stress at elevated temperatures.
6. A Study of Young's modulus of elasticity, E, and the modulus of rigidity G (or of Poisson's ratio) of metals at high temperature.

On the basis of the reports of the task groups, the Panel proposes:

(*a*) Acceptance of cooperation offered by Mr. Nadai and Westinghouse, work to begin immediately on the subject "The Influence of the Surrounding Atmosphere or of Certain Gases, including Combustion Products in Gas Turbines, on the Creep of Metals and on the Fracture at High Temperatures."

(*b*) By consultation and discussion with Mr. Nadai and Westinghouse, to combine two or more of the remaining proposals, emphasizing the fundamental issues, beginning work on the new project as soon as a mutually agreeable program is reached.

These recommendations were subsequently approved by the Joint Committee.

Data and Publications Panel (R. F. Miller, chairman):

This panel developed the appended report, Appendix III, providing current information on many of the facilities that are available and in use for low-temperature as well as high-temperature testing. This information will be of much service to the Joint Committee, should be of interest to many of those concerned with research work in this field, and the data are available for use by the National Military Establishment.

This panel is continuing work on a questionnaire and data form and on an extensive program involving the development of latest information on properties of materials at elevated temperatures. It is also arranging for the publication in the near future of a compilation of valuable data on the chemical and physical properties of many carbon and alloy steels which are used for elevated temperature service. This report will eventually be supplemented by the information coming from the more extensive survey now being planned.

Funds in the hands of The American Society of Mechanical Engineers for the credit of the Committee amounted to $10,587.74 as of June 30, 1949. Of these funds, the unexpended portion of the $4000 authorized for Project 29, Minute No. 1550, is earmarked to cover a contract with Battelle Memorial Institute in connection with the work on that Project. Another $1000 is earmarked for work on non-ferrous metals.

No technical program was sponsored at this time, but a technical session is scheduled for the Annual Meeting of the American Society of Mechanical Engineers in New York in December, 1949.

This report was unanimously approved subject to editorial changes by the 21 members of the committee present or represented at the meeting on June 30, 1949, out of a total membership of 27. There were no negative votes.

Respectfully submitted on behalf of the committee,

ERNEST L. ROBINSON,
Chairman.

H. C. CROSS,
Secretary.

APPENDIX 1

EFFECT OF VARIABLES ON THE CREEP RESISTANCE OF STEELS

(PROJECT No. 18)

PREPARED BY H. C. CROSS

At the meeting of December 2, 1948, four questions were referred to the Project Committee. These questions were put to the Advisory Committee by letter. Answers were received from four of the five members.

1. Three favor purchasing basic open-hearth ingots in which the desired silicon and aluminum contents are obtained by mold additions. The fourth member favors testing only commercial composition steels.

2. Carnegie-Illinois Steel Corp. has offered to prepare the desired steels. A basic open-hearth coarse-grain practice melt is soon to be made with 0.15 per cent carbon and 0.30 to 0.60 per cent manganese contents, and with an aluminum addition of about $\frac{1}{3}$ lb. per ton in the ladle. Ingot additions will be made to give ingots with 0.35 per cent silicon and aluminum at 1.25 and 2.5 lb. per ton, and an ingot with 0.50 to 0.60 per cent silicon with 2.5 lb. aluminum per ton. These three ingots, along with one of base heat will be processed to supply 200 ft. of 1-in. round stock of each. These ingots will give a suitable range of silicon-aluminum ratios in ingots from the same heat.

3. One member wished to test commercial analysis steel, but the desired purpose of determining the effect of the silicon-aluminum ratio on creep properties cannot be carried out with steel of 0.25 per cent silicon maximum. Three members agree that steels of suitable silicon content should be obtained.

4. Steels containing 0.15 per cent silicon have already been tested. It is desired to test steels with 0.10 and 0.35 and 0.50 per cent silicon to complete the picture on effect of silicon-aluminum ratio.

For all of these steels, grain-coarsening characteristics will be determined, and creep resistance at 850 F. will be determined when heat treated to produce both fine and coarse austenite grain sizes. If indicated desirable by the results, experiments to determine critical cooling rates for good creep resistance will be made.

The completion of this project with a maximum expenditure of $3500 was authorized by the Joint Committee on June 30, 1949.

APPENDIX II

STABILITY OF STEELS AS AFFECTED BY TEMPERATURE

(Project No. 29)

Prepared by J. J. Kanter

Laboratory test data of graphitization susceptibility near welded joints of steels for modern steam-power piping have been presented in four earlier reports. A study of casting steels was sponsored by the Manufacturers Standardization Society of the Valve and Fittings Industry with Chapman Valve Manufacturing Co., Crane Co., Edward Valves, Inc., Lunkenheimer Co., William Powell Co., Reading-Pratt and Cady Division of the American Chain and Cable Co., and Walworth Co. cooperating. Initially, carbon-molybdenum (WC1) and ½ per cent chromium-molybdenum (WC3) steels were subjected to testing and results of examinations after almost three years aging at 1025 F. were made available last year. Further studies are being made only after rather long intervals of aging, and the few additional examinations in the last year show no new developments in these materials. Since these tests hold little promise of furthering our knowledge of graphitization phenomena, it is planned to conclude this study after 35,000 hr. aging.

After the above program had been under way for about a year, it was apparent that more highly-alloyed casting steels should be investigated also. Accordingly, welded specimens of nickel-chromium-molybdenum (WC4), 1.25 per cent chromium-molybdenum (WC6) and 2 per cent chromium-molybdenum (C3A) steels together with additional 0.5 per cent chromium-molybdenum (WC3) steels were aged at 1100 F. To date, after 20,000 hr. (about 2½ years) exposure, none of these materials has developed any graphite.

The effect of welding variables on the graphitization process in 0.5 per cent chromium-molybdenum (A280) seamless steel pipe was studied by the Pipe Fabrication Institute with American Locomotive Co., Crane Co., Grinnell Co., M. W. Kellogg Co., and Pittsburgh Piping and Equipment Co. cooperating. This material continues to be resistant to graphite formation through 20,000 hr. (about 2½ years) aging at 1100 F.

While practical means of combatting graphite formation near welded joints in elevated temperature service are well established, studies of a more fundamental nature are needed to clarify our understanding of the mechanisms involved. At Battelle Memorial Institute, Project No. 29 is sponsoring an investigation of carbides extracted from certain plain low-carbon steels of varying graphitization susceptibilities. After preliminary tests to determine optimum operating conditions, electrolytic extraction of a specimen anode, contained in a semi-permeable plastic membrane in ammonium chloride–citric acid solution, was conducted on one of the susceptible steels and the residue analyzed for eight constituents by wet chemical methods. Furthermore, total aluminum content has been checked spectrographically by converting the residue to oxide and comparing with synthetic iron oxide standards containing known amounts of aluminum oxide. Also, an X-ray diffraction examination has been made. All four of the steels included in the test program have been analyzed for certain special elements as shown below:

All values in per cent

Specimen	Soluble Aluminum	Insoluble Aluminum	Nitrogen,[a] G.E. Co.	Oxygen,[b] B.M.I.	Hydrogen,[b] B.M.I.	Nitrogen,[b] B.M.I.	Graphitization Characteristics
No. K1...	0.005	0.009	0.0056	0.013	0.00005	0.005	Resistant[c]
No. 5B...	0.005	0.002	0.006	0.007	0.00004	0.005	Susceptible
No. G20..	0.020	0.003	0.008	0.002	0.00004	0.005	Susceptible
No. G21..	0.005	0.003	0.0079	0.004	0.00009	0.004	Resistant

[a] Standard Kjeldahl method with results checked by titration and colorimetric means.

[b] Total vacuum fusion method; precision ±0.001 per cent for O_2, ±0.00004 per cent for H_2, and ±0.001 per cent for N_2.

[c] Relatively resistant, but developed graphite after 6000 hr. aging at 1025 F.

Analysis of residue extracted from steel 5B as spheroidized and comparison with analysis of the steel is presented below:

Constituent	Residue Analysis Weight, per cent	Residue on Steel Basis Weight, per cent	Steel Analysis Weight, per cent
Al (Soluble)	0.11	0.0029	0.005
Al_2O_3	0.14	0.0037	0.004
Si (Soluble)	0.12	0.0032	0.224[a]
SiO_2	0.58	0.0154	....
C	7.15	0.190	0.20
Mn	3.25	0.0863	0.57
Fe	84.2	2.24	Balance
S	0.28	0.0074	0.032
Total	95.83		

[a] Total silicon content.

These results are reasonably consistent with the view that the residue is chiefly cementite containing some manganese and approximated by the formula $(Fe\ Mn)_3C$. Significance of the soluble aluminum content of the residue has not been ascertained, but attention will be directed toward clarifying this point. X-ray diffraction analysis shows only a strong pattern of cementite (Fe_3C) and a very faint pattern of what may be kappa alumina. When similar data on the other steels are made available, additional information may be deduced as to the mechanism of carbide reversion to graphite.

Acknowledgment:

Steels for this study were supplied by Battelle Memorial Institute, Crane Co., and National Tube Co. Nitrogen analyses by the standard Kjeldahl method were made by the General Electric Co.

To date, a total of $2276.64 has been spent on this study. It is estimated that about five months more work is required to complete the program, and, at the present rate of expenditure, this effort will consume substantially all of the initial appropriation of $4000. A complete report of the entire investigation would then be forthcoming.

APPENDIX III

HIGH-TEMPERATURE AND LOW-TEMPERATURE TESTING EQUIPMENT IN THE UNITED STATES[1]

RESULTS OF QUESTIONNAIRE CONDUCTED AMONG TESTING LABORATORIES

In 1940, the ASTM-ASME Joint Committee on Effect of Temperature on the Properties of Metals conducted a survey of the high-temperature testing equipment in this country. Considerable expansion of these facilities has occurred during the past nine years, rendering the original survey obsolete. The Joint Committee therefore undertook a revision of this survey, including low-temperature as well as high-temperature testing facilities.

The members of the Data and Publications Panel, to whom the task of conducting the Survey was assigned, prepared a selected list of laboratories who might possibly have such equipment, and circulated a questionnaire among them. Out of 319 inquiries sent out on June 25, 1948, 267 laboratories have replied. Of these, 112 indicated that they had equipment, and supplied the requested information, and a second group of 155 laboratories stated that they did not have this type of equipment. A third group of 52 laboratories have not replied.

The completed questionnaires are contained in the five volumes which comprise this 1949 Survey of High-Temperature and Low-Temperature Testing Equipment. Two copies of the complete survey were prepared, one for the Research and Development Board of the National Military Establishment in Washington, D. C., and the other for retention by the Data and Publications Panel of the Joint Committee. A summary of this survey is given below. It is suggested that inquiries for more detailed information regarding the test methods or results be addressed to the laboratory conducting the work:

No. 1.—Tension Tests

Allegheny Ludlum Steel Corp.
Allis-Chalmers Mfg. Co.
Aluminum Company of America
American Brake Shoe Co.
Armco Steel Corp.
American Steel and Wire Co.
Babcock & Wilcox Co.
Baker and Co., Inc.
Battelle Memorial Institute
Bell Aircraft Corp.
Bethlehem Steel Co., Inc.
Blaw-Knox Co.
Boeing Airplane Co.
California, University of
Carnegie-Illinois Steel Corp.
Carpenter Steel Co.
Case Institute of Technology
Caterpillar Tractor Co.
Chapman Valve Mfg. Co.
Chase Brass and Copper Co. Inc.
Chrysler Corporation
Climax Molybdenum Co.
Cornell Aeronautical Lab., Inc.
Crane Co.
Crucible Steel Company of America
Cummins Engine Co., Inc.

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[1] Prepared by Data and Publications Panel:
R. F. Miller, *Chairman*
J. W. Bolton
C. L. Clark
H. C. Cross
C. T. Evans, Jr.
A. J. Herzig
J. J. Kanter
V. T. Malcolm
N. L. Mochel
P. G. McVetty
E. L. Robinson
Leo Schapiro
G. V. Smith
J. S. Worth

Denver & Rio Grande Western RR Co.
Douglas Aircraft Co., Inc.
Dow Chemical Co.
Driver-Harris Co.
duPont de Nemours, E.I., & Co. Inc.
Edward Valves, Inc.
Elliott Co., Inc.
Fansteel Metallurgical Corp.
Ford Motor Co.
General Electric Co.
General Motors Corp.
Goodyear Aircraft Corp.
Haynes Stellite Co.
Herron, James H., Co.
Illinois Institute of Technology
Illinois, University of
Inland Steel Co.
International Harvester Co.
International Nickel Co., Inc.
Jones & Laughlin Steel Corp.
Kellogg, M. W., Co.
Kentucky, University of
Lockheed Aircraft Corp.
Lunkenheimer Co.
Marquette, University of
Martin Co.
Michigan, University of
Midvale Co.
National Bureau of Standards
National Tube Co.
Naval Air Experimental Station
Naval Research Laboratory
New York Testing Laboratories, Inc.
North American Aviation, Inc.
N. C. State College of Agriculture and Engineering
Ohio Steel Foundry Co.
Ohio State University
Pennsylvania, University of
Pittsburgh Testing Laboratory
Powell, Wm., Co.
Republic Steel Corp.
Robinson Labs., Inc.
Smith, A. O., Corp.
Studebaker Corp.
Standard Oil Development of N. J.
Syracuse University
Thompson Products, Inc.
Tour, Sam and Co., Inc.
Tube Turns, Inc.
Union Carbide and Carbon Corp.
U. S. Naval Engineering Experimental Station
U. S. Steel Corp. of Delaware
Watertown Arsenal
Westinghouse Electric Corp.
Wright Aeronautical Corp.
Wright-Patterson Air Force Base

No. 2.—Compression Tests

American Brake Shoe Co.
Bell Aircraft Corp.
California, University of
Case Institute of Technology
Chapman Valve Mfg. Co.
Cummins Engine Co., Inc.
Dow Chemical Co.
Edward Valves, Inc.
International Nickel Co., Inc.
Kellogg, M. W., Co.
Martin Co.
National Bureau of Standards
New York Testing Laboratories, Inc.
North American Aviation, Inc.
N. C. State College of Agriculture and Engineering
Ohio State University
Tour, Sam and Co., Inc.
U. S. Naval Engineering Experimental Station.
Watertown Arsenal
Westinghouse Electric Corp.
Wright-Patterson Air Force Base
General Electric Co.
Goodyear Aircraft Corp.

No. 3.—Controlled Strain Rate Tests

Battelle Memorial Institute
California, University of
Chicago, University of
Chrysler Corp.
General Electric Co.
Haynes Stellite Co.
Lunkenheimer Co.
Pennsylvania, University of
North American Aviation, Inc.
Tube Turns, Inc.
Westinghouse Electric Corp.

No. 4.—Creep Tests

Allegheny Ludlum Steel Corp.
Aluminum Company of America
American Brake Shoe Co.
Armco Steel Corp.
Babcock & Wilcox Co.
Battelle Memorial Institute
Bethlehem Steel Co., Inc.
Boeing Airplane Co., Inc.

California, University of
Chapman Valve Mfg. Co.
Chase Brass and Copper Co.
Chrysler Corp.
Cornell Aeronautical Lab., Inc.
Crane Co.
Crucible Steel Co. of America
Douglas Aircraft Co., Inc.
Dow Chemical Co.
Edward Valves, Inc.
Elliott Co., Inc.
General Electric Co.
Great Lakes Steel Corp.
Illinois, University of
International Nickel Co., Inc.
Haynes Stellite Co.
Kellogg, M. W., Co.
Lunkenheimer Co.
Michigan, University of
Midvale Co.
National Bureau of Standards
National Tube Co.
Naval Air Experimental Station
New Jersey Zinc Co. (of Pa.)
North American Aviation, Inc.
Standard Oil Development Co. of N. J.
Syracuse University
Thompson Products, Inc.
Union Carbide and Carbon Corp.
Union College
U. S. Naval Engineering Experiment Station
U. S. Steel Corp. of Delaware
Watertown Arsenal
Westinghouse Electric Corp.
Wright-Patterson Air Force Base
Wright Aeronautical Corp.

No. 5.—Rupture Tests

Allegheny Ludlum Steel Corp.
Allis-Chalmers Mfg. Co.
Aluminum Company of America
American Brake Shoe Co.
Armco Steel Corp.
Babcock & Wilcox Co.
Battelle Memorial Institute
Bethlehem Steel Co., Inc.
Boeing Airplane Co.
California, University of
Carnegie-Illinois Steel Corp.
Chapman Valve Mfg. Co.
Chase Brass and Copper Co., Inc.
Chrysler Corp.
Crane Co.
Crucible Steel Company of America
Dow Chemical Co.
Edward Valves, Inc.
Elliott Co., Inc.
General Electric Co.
General Motors Corp.
Haynes Stellite Co.
Illinois, University of
International Nickel Co., Inc.
Kellogg, M. W., Co.
Lunkenheimer Co.
Massachusetts Institute of Technology
Michigan, University of
Midvale Co.
National Tube Co.
Naval Air Experimental Station
Naval Research Laboratory
North American Aviation, Inc.
Powell, Wm., Co.
Standard Oil Development of N. J.
Syracuse University
Thompson Products, Inc.
U. S. Naval Engineering Experiment Station
U. S. Steel Corp. of Delaware
Union Carbide & Carbon Corp.
Watertown Arsenal
Wright Aeronautical Corp.
Wright-Patterson Air Force Base
Westinghouse Electric Corp

No. 6.—Relaxation Tests

Allegheny Ludlum Steel Corp.
Babcock & Wilcox Co.
California, University of
Chapman Valve Mfg. Co.
Crane Co.
Crucible Steel Company of America
Dow Chemical Co.
General Electric Co.
International Nickel Co., Inc.
Michigan, University of
Naval Research Laboratory
U. S. Naval Engineering Experiment Station
Westinghouse Electric Corp.
Wright Aeronautical Corp.

No. 7.—Torsion Tests

Allegheny Ludlum Steel Corp.
Battelle Memorial Institute
Bell Aircraft Corp.
California, University of
Carnegie-Illinois Steel Corp.
Carpenter Steel Co.
Driver-Harris Co.
Ford Motor Co.

General Electric Co.
Globe Steel Tubes Co.
Kellogg, M. W., Co.
Michigan, University of
National Tube Co
New York Testing Labs., Inc.
N. C. State College of Agriculture and Engineering
Republic Steel Corp.
Tour, Sam and Co., Inc.

No. 8.—Bend Tests

Allegheny Ludlum Steel Corp.
Battelle Memorial Institute
Bell Aircraft Corp.
California, University of
Case Institute of Technology
General Electric Co.
Goodyear Aircraft Corp.
Illinois, University of
Naval Air Experimental Station
New York Testing Laboratories, Inc.
Powell, Wm., Co.
Tour, Sam and Co., Inc.
U. S. Steel Corp. of Delaware
Watertown Arsenal
Westinghouse Electric Corp.
Wright-Patterson Air Force Base

No. 9.—Fatigue Tests

Allegheny Ludlum Steel Corp.
Aluminum Company of America
American Brake Shoe Co.
Associated Spring Co.
Battelle Memorial Institute
Bell Aircraft Co.
Boeing Airplane Co.
California, University of
Chase Brass and Copper Co., Inc.
Cornell Aeronautical Laboratory, Inc.
Crucible Steel Co. of America
Dow Chemical Co.
Edward Valves, Inc.
Elliott Co.
General Electric Co.
Illinois, University of
Kellogg, M. W., Co.
Marlin-Rockwell Corp.
Naval Air Experimental Station
Naval Research Laboratory
New York Testing Laboratories, Inc.
N. C. State College of Agriculture and Engineering
Ohio State University
Syracuse University
Thompson Products, Inc.
U. S. Naval Engineering Experiment Station
Watertown Arsenal
Westinghouse Electric Corp.
Wright Aeronautical Corp.
Wright-Patterson Air Force Base

No. 10.—Combined Stress Tests

California, University of
Case Institute of Technology
General Electric Co.
General Motors Corp.
Georgia School of Technology
Kellogg, M. W., Co.
Thompson Products, Inc.
Westinghouse Electric Corp.

No. 11.—Impact Tests

Allegheny Ludlum Steel Corp.
Aluminum Company of America
American Brake Shoe Co.
Armco Steel Corp.
American Steel Foundries
Babcock & Wilcox Co.
Battelle Memorial Institute
Bell Aircraft Corp.
Bethlehem Steel Co., Inc.
Blaw-Knox Co.
California, University of
Carnegie-Illinois Steel Corp.
Carpenter Steel Co.
Case Institute of Technology
Caterpillar Tractor Co.
Chapman Valve Mfg. Co.
Chase Brass and Copper Co.
Climax Molybdenum Co.
Coleman & Co.
Crane Co.
Crucible Steel Co. of America
Cummins Engine Co., Inc.
Denver & Rio Grande Western RR Co.
Edward Valves, Inc.
General Electric Co.
General Motors Corp.
Georgia School of Technology
Globe Steel Tubes Co.
Goodyear Aircraft Corp.
Herron, James, Co.
Illinois, University of
Inland Steel Co.
International Nickel Co., Inc.
Jones & Laughlin Steel Corp.

Kellogg, M. W., Co.
Kentucky, University of
Lunkenheimer Co.
Martin Co.
Michigan, University of
Midvale Co.
National Bureau of Standards
National Tube Co.
New York Testing Laboratories, Inc.
N. C. State College of Agriculture and Engineering
Ohio Steel Foundry Co.
Ohio State University
Pennsylvania, University of
Pittsburgh Testing Laboratory
Powell, Wm., Co.
Republic Steel Corp.
Souther Engineering Co.
Sun Oil Co.
Thompson Products, Inc.
Standard Oil Development of N. J.
Tour, Sam and Co., Inc.
Tube Turns, Inc.
Union Carbide & Carbon Corp.
U. S. Naval Engineering Experiment Station
U. S. Steel Corp. of Delaware
Vogt, Henry, Machine Co.
Watertown Arsenal
Westinghouse Electric Corp.
Wright Aeronautical Corp.

No. 12.—Hardness Tests

Allegheny Ludlum Steel Corp.
Aluminum Company of America
American Brake Shoe Co.
Armco Steel Corp.
Battelle Memorial Institute
Bell Aircraft Co.
California, University of
Carpenter Steel Co.
Caterpillar Tractor Co.
Chapman Valve Mfg. Co.
Climax Molybdenum Co.
Crane Co.
Crucible Steel Co. of America
Dow Chemical Co.
Edward Valves, Inc.
Ford Motor Co.
General Electric Co.
General Motors Corp.
Georgia School of Technology
Goodyear Aircraft Corp.
Jones & Laughlin Steel Corp.
International Nickel Co., Inc.
Latrobe Electric Steel Co.
Lunkenheimer Co.
New York Testing Laboratories, Inc.
Ohio State University
Pittsburgh Testing Laboratory
Powell, Wm., Co.
Thompson Products, Inc.
Tour, Sam and Co., Inc.
Union Carbide & Carbon Corp.
U. S. Naval Engineering Experiment Station
U. S. Steel Corp. of Delaware
Watertown Arsenal
Westinghouse Electric Corp.

No. 13.—Thermal Conductivity

Battelle Memorial Institute
Bell Aircraft Corp.
National Bureau of Standards
Naval Air Experimental Station
New York Testing Laboratories, Inc.
New Jersey Zinc Co. (of Pa.)
Pfaudler Co.
Westinghouse Electric Corp.

No. 14.—Thermal Expansion

Allegheny Ludlum Steel Corp.
Allis-Chalmers Mfg. Co.
Aluminum Company of America
American Brake Shoe Co.
Armco Steel Corp.
Baker and Co., Inc.
Battelle Memorial Institute
Bell Aircraft Corp.
Bethlehem Steel Co., Inc.
Carpenter Steel Co.
Chapman Valve Mfg. Co.
Climax Molybdenum Co.
Crane Co.
Crucible Steel Co. of America
Driver-Harris Co.
Edward Valves, Inc.
Ford Motor Co.
General Electric Co.
International Harvester Co.
International Nickel Co., Inc.
Jones & Laughlin Steel Corp.
Kellogg, M. W., Co.
Lunkenheimer Co.
Massachusetts Institute of Technology
Michigan State College
Michigan, University of
Midvale Co.

National Bureau of Standards
Naval Air Experimental Station
Ohio State University
Pennsylvania, University of
Pittsburgh Testing Laboratory
Powell, Wm., Co.
Republic Steel Corp.
Standard Oil Development of N. J.
Syracuse University
Thompson Products, Inc.
Tour, Sam and Co., Inc.
Union Carbide & Carbon Corp.
U. S. Naval Engineering Experiment Station
U. S. Steel Corp. of Delaware
Watertown Arsenal
Westinghouse Electric Corp.
Wisconsin, University of

No. 15.—Corrosion Tests (Including Stress-Corrosion)

Armco Steel Corp.
Battelle Memorial Institute
Chrysler Corp.
Crane Co.
Crucible Steel Co. of America
Driver-Harris Co.
Ford Motor Co.
General Electric Co.
International Nickel Co., Inc.
Lunkenheimer Co.
Massachusetts Institute of Technology
Michigan, University of
National Bureau of Standards
Naval Air Experimental Station
Ohio State University
Tour, Sam and Co., Inc.
U. S. Naval Engineering Experiment Station
U. S. Steel Corp. of Delaware
Watertown Arsenal
Westinghouse Electric Corp.

No. 16.—Damping

Battelle Memorial Institute
California, University of
General Electric Co.
Syracuse University
U. S. Naval Engineering Experiment Station
Westinghouse Electric Corp.

No. 17.—Modulus of Elasticity

Allis-Chalmers Mfg. Co.
Aluminum Company of America
American Brake Shoe Co.
Babcock & Wilcox Co.
Battelle Memorial Institute
Bell Aircraft Corp.
Bethlehem Steel Co., Inc.
California, University of
Caterpillar Tractor Co.
Chapman Valve Mfg. Co.
Climax Molybdenum Co.
Crane Co.
Crucible Steel Co. of America
Electro Refractories & Alloys Corp.
Goodyear Aircraft Corp.
Lunkenheimer Co.
Midvale Co.
New York Testing Laboratories, Inc.
Ohio State University
Pittsburgh Testing Laboratory
Powell, Wm., Co.
Standard Oil Development Co. of N. J.
Syracuse University
Thompson Products, Inc.
U. S. Naval Engineering Experiment Station
General Electric Co.
U. S. Steel Corp. of Delaware
Watertown Arsenal
Westinghouse Electric Corp.
Wright-Patterson Air Force Base

No. 18.—X-Ray Diffraction

American Brake Shoe Co.
Baker & Co.
Battelle Memorial Institute
California, University of
Dow Chemical Co.
Ford Motor Co.
General Electric Co.
Massachusetts Institute of Technology
National Bureau of Standards
Naval Air Experimental Station
Tour, Sam and Co., Inc.
U. S. Naval Engineering Experiment Station
U. S. Steel Corp. of Delaware
Watertown Arsenal
Westinghouse Electric Corp.
Wisconsin, University of

No. 19.—Equipment for Studying Effect of Temperature on Properties of Ceramics

American Brake Shoe Co.
Babcock & Wilcox Co.
Battelle Memorial Institute
Bethlehem Steel Co.

California, University of
Carnegie-Illinois Steel Corp.
Chrysler Corp.
Crane Co.
Ford Motor Co.
General Electric Co.
Georgia School of Technology
Illinois, University of
Massachusetts Institute of Technology
National Bureau of Standards
Naval Air Experimental Station
N. C. State College of Agriculture and Engineering
Ohio State University
Standard Oil Development Co. of N. J.
Tour, Sam and Co., Inc,

REPORT OF COMMITTEE C-1
ON
CEMENT*

Committee C-1 on Cement held three meetings during the past year: in Detroit, Mich., June 25, 1948, in St. Louis, Mo., October 28, 1948, and in Chicago, Ill., March 2, 1949. A good attendance of members and interested visitors was present at all of these meetings.

The committee records with sorrow the loss of two of its members by death, Lewis R. Ferguson and Howard H. Leh.

Joseph Brobston was made an Honorary Member of Committee C-1 in recognition of his long service on the committee which he joined about forty years ago.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1948 Annual Meeting, Committee C-1 presented to the Society through the Administrative Committee on Standards a revision of the Tentative Specifications for Air-Entraining Portland Cement (C 175 - 48 T). This recommendation was accepted by the Standards Committee on September 29, 1948, and the revised tentative appears in the 1948 Supplement to Book of A.S.T.M. Standards, Part II.

The Sponsoring Committee on Portland Cement (R. R. Litehiser, chairman) studied the various questions that arose within its scope. Particular attention was given to the chemical limits for type V cement, and air-entraining limits for cements in Specifications C 150, which led to revisions affecting these specifications presented later in this report. The study of current problems continues.

The Sponsoring Committee on Masonry Cement (H. D. Baylor, chairman) reported that test results had been received from most of the laboratories that had participated in the cooperative freezing-and-thawing tests of mortar bars prepared with masonry cements. The Sponsoring Committee had also made a study of six natural cements. Based on the sponsoring committee's recommendations, proposed revisions of Specifications C 10 and C 91 are presented elsewhere in this report.

The Sponsoring Committee on Blended Cements (L. R. Forbrich, chairman) reported improvement in the method for determining the strength of pozzolanic-lime-sand mortars. Steady progress has been made in the two cooperative series of tests sponsored by the subcommittee. The one series of tests is concerned with the development of a method for evaluating pozzolanic materials; the other with finding a reliable method for measuring the fineness of these materials.

The Working Committee on Methods of Chemical Analysis (W. C. Hanna, chairman) continued its studies of various problems, including direct determination of aluminum oxide, the removal of manganese, and the precipitation of calcium. In view of the present interest in alkalies in cements, a quick and accurate method for their determination has become very desirable.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27-July 1, 1949.

The subcommittee submitted a method involving the use of flame photometry which Committee C-1 is recommending for publication as tentative, as appended hereto.[1] This method has been recently made available as the result of cooperative work between the laboratories of the Lone Star Cement Corp. (L. R. Pritchard, Chief Chemist); the Portland Cement Association Fellowship at the National Bureau of Standards (R. H. Bogue, Director); and the Cement Analysis Laboratory at the National Bureau of Standards (B. L. Bean, in charge). This same method is being considered for inclusion in Federal specifications.

The Working Committee on Volume Change and Soundness of Portland Cement (H. F. Gonnerman, chairman) has prepared and is now circulating to Committee C-1 for information only, a proposed method of test for determining the potential alkali reactivity of cement-aggregate combinations by measurement of the expansion of mortar bars. The subcommittee is continuing its studies of this subject. Prompted by some recent experiences, the subcommittee presented certain proposed revisions in the Autoclave Test Method, C 151, which are mostly of a precautionary nature. Because of the safety features involved, the committee is recommending these changes, as set forth later in this report, for immediate adoption.

The Working Committee on Sulfate Resistance (D. Wolochow, chairman) completed a preliminary cooperative series of tests, and worked on the summary of results. Details for future work were developed in a recent well-attended meeting of subcommittee members and visitors.

The Working Committee on Time of Set (E. E. Berger, chairman) is studying current problems in its field, including the development of a method for measuring the degree of premature stiffening of cement. The subcommittee recommended that the Proposed Method of Test for Setting Time of Hydraulic Cement in Mortar, published as information as an appendix to the 1948 Report of Committee C-1,[2] be accepted as a new tentative.

The Working Committee on Heat of Hydration (W. J. McCoy, chairman) has studied details of the Standard Method of Test for Heat of Hydration of Portland Cement (C 186) and has presented, as information only at this time, certain suggested changes in that method. Future work has been planned.

The Working Committee on Bleeding, Plasticity, and Workability (H. L. Kennedy, chairman) has submitted the proposed Tentative Specifications for Flow Table for use in the Testing of Hydraulic Cements. In preparing these specifications, the subcommittee cooperated with the cement laboratory of the National Bureau of Standards, the Working Committee on Strength, and the Cement Reference Laboratory. The requirements are the same as are being considered for inclusion in the Federal specifications and are designed to secure a table that would give concordant results among laboratories and at the same time permit the use of the vast majority of the existing flow tables. Use has been made of the trial calibration sample developed in the Cement Reference Laboratory. The subcommittee is sponsoring a series of cooperative tests of bleeding of cements among a group of laboratories, using the procedure described in a paper presented at this Annual Meeting[3] by R. C. Valore, J. C. Bowling, and R. L. Blaine of the National Bureau of Standards staff.

The Working Committee on Fineness (R. L. Blaine, chairman) has been studying details relating to the turbidimeter and the air permeability tests for fineness. The subcommittee prepared certain editorial changes in Standard Method C 115, as given later in the report. Also, editorial changes in the Tentative Method C 204 were submitted by the subcommittee, as related later in this report. Thirty brands of portland cement were tested by the air permeability method and also by the turbidimeter methods, and the results were made available to the Sponsoring Committee on Portland Cement.

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[1] This method was accepted as tentative by the Society and appears in the 1949 Book of A.S.T.M. Standards, Part 3.

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 48, p. 250 (1948).

[3] See p. 891.

The Working Committee on Strength (G. L. Lindsay, chairman) continued its study of questions within its scope, including the effects of variations in the rate of loading of strength test specimens. An extensive series of tests has been sponsored by the subcommittee to develop information on the comparative relationship of the tensile, compressive and flexural strength of mortar to the flexural and compressive strength of concrete. Fifteen laboratories participated in these tests, using four cements. A lengthy compilation and study of the data was prepared and distributed to members of Committee C-1 and portions of that summary are now presented as Appendix I to this report.

The Working Committee on Additions (C. H. Scholer, chairman) has been active in studying questions relating to a possible change in policy regarding the acceptability of additions to cement in Tentative Specifications C 175. C. H. Scholer, the present subcommittee chairman, recently succeeded H. J. Gilkey who had been chairman of the subcommittee for some years but had resigned because of the pressure of other work. The change in policy regarding additions would involve the development of a suitable specification for materials to be used as air-entraining additions in Specifications C 175. The subcommittee has also given attention to questions that have arisen in the course of tests now being made for the producer of an addition that is now before the subcommittee for consideration.

The Working Committee on Coordination of Methods of Test (J. R. Dwyer, chairman) reviewed the Tentative Specifications for Flow Table for Use in the Tests of Hydraulic Cements, as appended to this report.[4] The subcommittee has recommended certain revisions in the requirements for glass graduates in keeping with recent developments in that field. The subcommittee also recommended a change in the requirements for temperatures of mixing water and storages in the various cement test methods, to keep in line with the efforts of A.S.T.M. and the government to standardize the requirements for laboratory atmospheric conditions as much as possible.

The Working Committee on SO_3 Content (H. S. Meissner, chairman) completed the initial phase of its extensive cooperative study of eight cements, each prepared with seven different amounts of gypsum. Six laboratories participated in the tests. A detailed extensive progress report was distributed to the members of Committee C-1. Work is being continued on the investigation, including the study of durability of the cements. In Appendix II to this report, there is presented a brief summary of the scope and current status of the investigation.

The Working Committee on Methods of Test for Air-Entrainment (H. K. Cook, chairman) has under study the plans for a proposed cooperative test program to investigate the possibility of using the flow table in lieu of the flow trough in Method C 185, and also study of other methods of determining the air content of mortar.

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[4] These specifications were accepted as tentative by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 3.

The Editorial Committee (W. J. McCoy, chairman) has been engaged in studying the details of the various cement specifications and test methods and has presented its findings from time to time for consideration by the respective subcommittees.

The Subcommittee on Cement Reference Laboratory (G. E. Warren, chairman) continued its supervision and counsel in the work of the Cement Reference Laboratory at the National Bureau of Standards. That laboratory, sponsored by Committee C-1, is a joint project of the Government and the A.S.T.M. and is supported by funds received through the National Bureau of Standards, the Public Roads Administration, and the A.S.T.M. Inspection of cement laboratories at various locations has been continued, although on a greatly reduced scale because of loss of personnel. One new man has been trained, and efforts are being continued to secure additional help. The three 200,000-lb. capacity proving rings have been received and calibrated and arrangements are now being made to enlarge the scope of the inspection service among cement testing laboratories. Additional work was done in studying the preparation and distribution of trial samples of the experimental mixture developed in the Reference Laboratory for the calibration of flow tables. The laboratory continued to cooperate with subcommittees in matters relating to methods and apparatus and was represented at meetings of certain Federal, A.A.S.H.O. and A.S.T.M. groups interested in matters relating to cement laboratory procedure and equipment. Miscellaneous work included the testing of a small number of pieces of cement testing equipment received at the Bureau for test by the Reference Laboratory.

NEW TENTATIVES

Tentative Method of Test for Sodium Oxide and Potassium Oxide in Portland Cement by Flame Photometry.[1]—Because of the present interests in alkalies in cement and the consequent desire for a quick and accurate method for their determination, the committee recommends the acceptance as tentative of this method, as appended to this report.[1] As explained earlier in this report, the proposed method has been the subject of cooperative study by a number of laboratories.

Tentative Method of Test for Setting Time of Hydraulic Cement in Mortar.—The committee recommends the acceptance as tentative of this test method which was published as information with the 1948 Report of Committee C-1,[2] with the following revisions:

Section 4(d).—Change the required plunger settlement in the test for consistency to read "20 ± 4 mm." instead of "20 ± 5 mm."

Tentative Specifications for Flow Table for Use in the Testing of Hydraulic Cements.—The committee recommends the acceptance as tentative of these specifications for the 10-in. flow table as appended to this report.[4] The small flow table has been used for many years, but earlier descriptions have not covered many of the details of design and mounting that, in cooperative studies and in the work of the Reference Laboratory, were found to play an important part in the performance of this apparatus.

Tentative Specifications for Natural Cement.[4]—The committee recommends the acceptance as tentative of these specifications which are in effect a tentative revision of the Standard Specifications C 10 and which, when adopted, will replace them.

TENTATIVE REVISION OF STANDARD

Standard Specifications for Portland Cement (C 150 - 47).[5]—The committee recommends the acceptance of the following tentative revision to provide a limit on the air-entraining properties of the cements covered by these specifications.

Table II.—Add the following requirement to this table: "Air content of mortar, prepared and tested in accordance with Method C 185, maximum per cent by volume, less than 15.0 for all types."

In order to make footnote *c* of this table consistent with the corresponding footnotes in Tentative Specifications C 175 and in the Federal specifications, and at the same time provide a more meaningful requirement, the committee recommends that the last sentence of footnote *c* be changed to read: "if, at the option of the purchaser, a 7-day test is required on type III cement, the strength at 7 days shall be higher than at 3 days."

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends revisions for immediate adoption in the following standards and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society.

Standard Specifications for Portland Cement (C 150 - 47):[5]

Table I.—Delete the present limitations on aluminum oxide (Al_2O_3) and ferric oxide (Fe_2O_3) for type V cement and add the following footnote to this table: "The tricalcium aluminate shall not exceed 5 per cent, and the tetracalcium aluminoferrite plus twice the amount of tricalcium aluminate shall not exceed 20 per cent."

Add the following formula to footnote *d:* "Tetracalcium aluminoferrite (C_4AF) = 3.04 × per cent Fe_2O_3."

Standard Method of Test for Autoclave Expansion of Portland Cement (C 151 - 43):[6] In order to secure a suitable pressure gage, and at the same time stress the importance of observing safety precautions in the use of the autoclave, the following revisions are recommended:

Section 2.—In Paragraph (*c*), change the fifth sentence to read: "The sides of the molds shall be sufficiently rigid to prevent spreading or warping."

Add the following as a new Paragraph (*d*) to this section: "(*d*) Trowel.—The trowel shall have a steel blade, 4 to 6 in. in length, with straight edges."

Reletter the present Paragraph (*d*) as (*e*), and add the following description of the pressure gage to the end of the paragraph: "The pressure gage shall have a dial diameter of nominally $4\frac{1}{2}$ in. and shall be graduated from 0 to 600 psi. with scale divisions of not more than 5 psi. The error in the gage shall not exceed plus or minus 3 psi. at the operating pressure of 295 psi."

Reletter the present Paragraph (*e*) as (*f*) and in the last sentence, add "having an insulating grip" after "steel reference bar."

Section 5 (*b*).—In the fourth sentence, italicize the words "and any pressure remaining shall be slowly released by partially opening the vent valve until atmospheric pressure is attained."

Section 7.—In the second sentence, delete the irrelevant words "and time of setting."

Insert the following note as a prominent note in Section 1 since it covers a warning in making autoclave tests: "NOTE.—For safety precautions to be observed in making autoclave tests of cement, see Sections 35 to 37 of the Manual of Cement Testing."

Standard Specifications for Masonry

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[5] 1947 Supplement to Book of A.S.T.M. Standards, Part II.

[6] 1946 Book of A.S.T.M. Standards, Part II.

Cement (C 91 - 48):[7]—In order to provide for two types of masonry cement, and to avoid having two sets of strength requirements with possible resultant confusion, the committee recommends the following revisions for immediate adoption:

Section 1.—Change to read as follows:

> 1. These specifications cover two types of masonry cement, as follows:
>
> *Type I.*—This type of masonry cement is for use in general purpose masonry.
>
> *Type II.*—This type of masonry cement is for use where high strength is required.

Section 4.—Change to read as follows:

> 4. *Type I.*—The average compressive strength of 2-in. mortar cubes, made, stored, and tested in accordance with Sections 19 to 29, shall be not less than 250 psi. at the age of 7 days. The average strength at 28 days shall be not less than 500 psi.
>
> *Type II.*—The average compressive strength of 2-in. mortar cubes, made, stored, and tested in accordance with Sections 19 to 29, shall be not less than 500 psi. at the age of 7 days. The average strength at 28 days shall be not less than 1000 psi.

Revisions in Glass Graduates Applicable to Various Cement Testing Methods.—In order to provide for the acceptance of glass graduates that may be marked according to accepted good practice of omitting certain of the lowest graduation lines, the committee recommends for immediate adoption the appropriate changes in the sentences relating to graduates in the various cement testing methods, the changes to be so done as to effect uniformity between those paragraphs, so far as possible, in the general description of the graduates.

The schedule governing the omission of graduation lines is as follows:

Capacity, ml.	Graduation lines
5 and 10	no change
25	omit lowest 2 ml.
50, 100, and 150	omit lowest 5 ml.
200 and 250	omit lowest 10 ml.
500	omit lowest 25 ml.

Standard Laboratory Conditions.—For the purpose of keeping in accord with the efforts now being made in Federal and A.S.T.M. circles to standardize and simplify the requirements for laboratory atmospheric conditions, the committee recommends that the wording of the cement test methods be so revised that the temperature requirement for the mixing water, moist air storage, water storage, and the storage for the vials in the heat of hydration test will read "23 ± 1.7C." instead of "21 ± 1.7C."

ADOPTION OF TENTATIVE REVISION AS STANDARD

The committee recommends the adoption as standard of the tentative revision of the Standard Specifications for Portland Cement (C 150 - 47).[5]

EDITORIAL CHANGES

Standard Method of Test for Fineness of Portland Cement by the Turbidimeter (C 115 - 42).[6]—The committee recommends the following changes that are of an editorial nature and are intended to clarify certain details of the specifications so as to insure that the present design and practice of using screw elevators and a hood over the photoelectric cell will be continued. The changes are as follows:

Figure 1.—Add the necessary broken lines to the outline of the photoelectric cell assembly to indicate the hood more clearly. Show the lower end of the stirring brush as rounded, in line with good practice of past years, instead of flat as now shown.

Section 2.—Change last sentence to read: "The apparatus shall consist specifically of the parts described in Sections 3 to 8 and shall be constructed in accordance with the detailed design and dimensional requirements shown in Fig. 1, except that the case may be of either wood or metal."

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[7] 1948 Supplement to Book of A.S.T.M. Standards, Part II.

Section 3(e).—Change the last sentence to read: "A hood shall be mounted over the photoelectric cell, with a horizontal slot $\frac{1}{2}$ in. in height by $1\frac{3}{8}$ in. in width. The front of the hood shall be $1 \pm \frac{1}{16}$ in. in front of the face of the cell."

Tentative Method of Test for Fineness of Portland Cement by Air Permeability Apparatus (C 204 - 46 T).[6]—The committee recommends the following editorial changes:

Section 2 (b).—Change the cell depth from "5.0 ± 0.5 cm." to "5.0 ± 1.5 cm."

Section 2 (c).—Change the required number of holes in disk from "25 to 35" to "30 to 40."

Section 2 (f).—Change the distance from the top of the side outlet to the bottom of manometer from "25 to 28 cm." to "25.0 to 30.5 cm."

Figure 1.—Change the tolerance of length of manometer from the lowest mark to the top of side arm outlet from "12.5 to 14.0 cm." to "12.5 to 14.5 cm."

These changes in dimensions of the air-permeability apparatus will not exclude any equipment manufactured to meet the earlier tolerances, will not affect the results of the tests, and will bring the instrument as specified in line with manufacturing practice.

Tentative Methods of Chemical Analysis of Portland Cement (C 114 - 48 T).[7]—To aid in achieving standardization in the requirements for the Jones reductor used in A.S.T.M. methods, the committee recommends that the requirements given for it in Section 11 (*a*) of Methods C 114 be changed to conform to those given in Recommended Practices for Apparatus and Reagents for Chemical Analysis of Metals (E 50 - 48).[8]

TENTATIVE CONTINUED WITHOUT REVISION

The committee recommends that the Tentative Method of Test for Air Content of Air-Entraining Portland-Cement Mortar (C 185 - 47 T),[5] because of a currently planned study of some questions relating to this method, be retained as tentative without revision other than a change in the requirements for temperature and for glass graduates as mentioned earlier in this report.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[9]

This report has been submitted to letter ballot of the committee, which consists of 85 voting members, of whom 71 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

F. H. JACKSON,
Chairman.

G. E. WARREN,
Secretary.

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[8] 1946 Book of A.S.T.M. Methods of Chemical Analysis of Metals.

[9] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee C-1 presented to the Society through the Administrative Committee on Standards a tentative revision of the Standard Method of Test for Compressive Strength of Hydraulic Cement Mortars (C 109 - 47). This recommendation was accepted by the Standards Committee on September 22, 1949, and the tentative revision appears in the 1949 Book of A.S.T.M. Standards, Part 3.

APPENDIX I

REPORT OF COOPERATIVE TESTS ON THE COMPARATIVE RELATIONSHIP OF TENSILE, COMPRESSIVE AND FLEXURAL STRENGTH OF MORTAR TO THE FLEXURAL AND COMPRESSIVE STRENGTH OF CONCRETE

Sponsored by Working Committee on Strength

Purpose

At the meeting of A.S.T.M. Committee C-1 held in Cincinnati, Ohio, on March 28, 1947, the Working Committee on Strength was given an assignment to explore the possibilities of developing a test for flexural strength of mortar which would be suitable for use as a specification test. It was thought that such a test might be found superior to either the A.S.T.M. method for tensile strength (C 190)[1] or compressive strength (C 109)[2] as an indicator of flexural strength of concrete.

The research laboratory of the Portland Cement Association furnished the Working Committee unpublished test data which included tensile, compressive, and flexural strength tests of standard mortar and flexural and compressive strength tests of concrete. A statistical study of these data indicated that the relationship of tensile, compressive, and flexural strength of standard mortar to the flexural strength of concrete was in a positive and fairly high degree of correlation. There were also indications that the compressive strength of C 109 mortar and the flexural strength of prisms made with C 109 mortar had a better correlation with flexural strength of concrete and that the C 109 compressive strength had considerably better correlation with the compressive strength of concrete than did the C 190 tensile strength.

The Working Committee decided, on the basis of the data studied that the assignment be broadened not only to explore the possibility of developing a flexural strength test of mortar but to consider also the comparative relationship of the tensile, compressive, and flexural strength of standard mortar to the flexural and compressive strength of concrete. A cooperative investigation was conducted for these purposes.

The following fifteen laboratories participated in this cooperative investigation:

Laboratory	*Individual*
California Division of Highways, Sacramento, Calif.	T. E. Stanton
Illinois Division of Highways, Springfield, Ill.	H. W. Russell
Iowa State Highway Commission, Ames, Iowa	Bert Myers
Minnesota Department of Highways, Minneapolis, Minn.	J. H. Swanberg
Missouri State Highway Dept., Jefferson City, Mo.	F. V. Reagel
National Bureau of Standards, Washington, D. C.	Herbert Insley
North Carolina State Highway and Public Works Commission, Raleigh, N. C.	C. E. Proudley
Ohio State, Department of Highways, Columbus, Ohio	R. R. Litehiser

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[1] Standard Method of Test for Tensile Strength of Hydraulic-Cement Mortars (C 190 - 44), 1946 Book of A.S.T.M. Standards, Part II, p. 80.

[2] Method of Test for Compressive Strength of Hydraulic-Cement Mortars (C 109 - 47), 1947 Supplement to Book of A.S.T.M. Standards, Part II, p. 43.

Pennsylvania Department of Highways, Harrisburg, Pa.	W. H. Herman
Portland Cement Assn., Chicago, Ill.	H. F. Gonnerman
Public Roads Administration, Washington, D. C.	E. F. Kelley
U. S. Bureau of Reclamation, Denver, Colo.	R. F. Blanks
Universal Atlas Cement Co., Buffington, Ind.	W. C. Hansen
U. S. Waterways Experiment Station, Clinton, Miss.	Herbert K. Cook
Washington State Department of Highways, Olympia, Wash.	Bailey Tremper

The laboratories are not listed in the order in which they appear in the tabulations of test data.

MATERIALS

Four portland cements were furnished to each laboratory. Each laboratory received approximately 380 lb. of each cement packed in a steel drum. The drums of a given cement were filled in such a manner that the cement would be the same in all drums. Each laboratory was also asked to mix the cement thoroughly in each drum before using it. The cements are identified as follows:

Cement	*Type*
A	I
B	IA
C	II
D	III

The cements were furnished and prepared for shipment by two manufacturers. One manufacturer furnished cement A and B from one plant and cement C from another plant, and the other manufacturer furnished cement D.

In addition many of the laboratories also made tests on some cements which they supplied. However, as will be explained later, the test data on these cements are not included in this report.

The standard and graded Ottawa sands and the concrete aggregates were furnished by each laboratory from its own supply.

DESCRIPTION OF TESTS

Each of the laboratories made three rounds of tests, one each generally on different days. Each test round consisted of the following tests and procedures:

1. *Tensile Strength of Mortar—A.S.T.M. Method C 190 - 44.*—Three specimens of each cement were tested at 3, 7, and 28 days except cement D which was tested at 1, 3, and 28 days.

2. *Compressive Strength of Mortar—A.S.T.M. Method C 109 - 47.*—Three specimens of each cement were tested at 3, 7, and 28 days except cement D which was tested at 1, 3, and 28 days.

3. *Flexural Strength of Mortar.*—Prisms having a 2 by 2-in. cross-section were made with graded Ottawa sand-mortar prepared and mixed in accordance with A.S.T.M. Method C 109 except the batch size was adjusted to give sufficient mortar for one specimen.

The prism molds were filled in two equal layers. Each layer was tamped a total of 60 times with the tamper specified in Method C 109 as follows:

> Fifteen tamps along each side of the mold with the 1-in. side of the tamper held parallel to the side of the mold and 30 tamps along the center line of the mold with the tamper held with the 1-in. side at right angles length of the mold.

Three prisms were made of each cement. They were stored in the moist cabinet for 20 to 24 hr. and then in water until tested. One specimen each was tested in flexure at the ages of 3, 7, and 28 days (1, 3, and 28 days for cement D). It was specified that the load should be applied at a rate such that the rate of increase in extreme fiber stress be not greater than 150 psi. per min. Some laboratories did not have testing machines with which they could attain this rate of loading, and this resulted in maxi-

TABLE I.—TENSILE AND COMPRESSIVE STRENGTH OF MORTAR

Each value is the average of nine specimens, three each made on different days.

Laboratory	Briquets—A.S.T.M. Method C 190				2-in. Cubes—A.S.T.M. Method C 109				
	Mixing water, per cent	Tensile Strength, psi.			Mixing Water, per cent	Flow, per cent	Compressive Strength, psi		
		3 days	7 days	28 days			3 days	7 days	28 days
				Cement A					
No. 1	10.4	320	410	459	50.0	109	1702	3042	**5095**
No. 2	10.5	344	463	523	52.0	106	1585	2833	**4767**
No. 3	10.3	334	422	497	50.0	106	1749	3105	**5102**
No. 4	10.3	320	397	448	52.0	107	1656	2958	**4703**
No. 5	10.4	325	414	462	50.0	110	1700	3017	**5066**
No. 6	10.5	316	418	479	51.2	110	1396	2543	**3865**
No. 7	10.4	322	415	484	52.8	108	1711	2872	**4740**
No. 8	10.3	349	424	485	52.0	112	2051	3473	**5723**
No. 9	10.3	342	437	507	54.5	104	1621	3022	**5228**
No. 10	10.3	334	404	471	51.0	110	1401	2529	**4304**
No. 11	10.3	298	389	457	52.1	110	1697	2917	**5131**
No. 12	10.3	297	401	476	50.0	109	1503	2731	**4541**
No. 13	10.4	330	395	424	51.4	105	1677	2867	**4485**
No. 14	10.4	350	445	475	52.8	104	1510	2685	**4730**
No. 15	10.4	323	410	448	51.0	101	1696	3047	**4722**
Avg.	10.4	327	416	473	51.5	107	1644	2909	**4814**
Percentage mean variation	....	4.2	3.6	4.0	....	....	6.8	5.3	**6.8**
				Cement B					
No. 1	10.4	276	358	413	49.0	108	1608	2938	**4753**
No. 2	10.3	310	438	500	51.0	108	1178	2332	**3969**
No. 3	10.3	292	387	452	48.9	109	1383	2672	**4255**
No. 4	10.4	257	346	390	50.0	108	1472	2711	**4189**
No. 5	10.3	271	383	446	49.0	112	1501	2858	**4518**
No. 6	10.5	285	380	434	48.6	106	1279	2557	**3744**
No. 7	10.4	333	404	462	51.2	108	1436	2647	**4143**
No. 8	10.4	317	389	459	50.0	113	1717	2981	**4576**
No. 9	10.3	329	440	491	54.3	110	1237	2455	**4486**
No. 10	10.3	306	367	438	50.0	106	1333	2490	**4089**
No. 11	10.3	297	363	403	49.3	109	1402	2747	**4194**
No. 12	10.4	283	399	450	49.0	108	1404	2708	**4481**
No. 13	10.5	290	369	429	50.0	100	1631	2999	**4360**
No. 14	10.4	275	370	435	52.1	108	1165	2295	**3770**
No. 15	10.5	281	389	422	51.0	106	1454	2894	**4300**
Avg.	10.4	294	386	442	50.2	108	1413	2686	**4255**
Percentage mean variation	....	6.0	5.1	4.	....	....	9.4	7.4	**5.6**
				Cement C					
No. 1	10.1	284	378	466	49.0	107	1679	2696	4906
No. 2	11.0	309	436	534	52.0	112	1477	2474	4369
No. 3	10.8	280	359	486	48.9	109	1493	2629	4667
No. 4	11.1	288	345	448	52.0	109	1422	2371	4289
No. 5	10.7	286	379	467	49.0	112	1593	2683	4677
No. 6	10.7	288	379	484	49.0	109	1290	2275	3872
No. 7	10.7	302	379	495	51.5	108	1458	2335	4165
No. 8	10.5	301	381	486	50.5	113	1947	3025	5709
No. 9	10.6	326	426	526	53.7	109	1444	2721	5025
No. 10	10.5	322	386	478	50.0	113	1297	2136	3861
No. 11	10.8	276	337	443	51.0	110	1584	2569	4614
No. 12	10.7	305	386	461	48.5	108	1487	2671	4731
No. 13	11.0	284	327	413	50.0	110	1562	2553	4488
No. 14	10.7	310	385	510	51.4	100	1415	2550	4635
No. 15	10.6	313	363	472	51.0	101	1559	2622	4600
Avg.	10.7	298	376	478	50.5	109	1514	2554	4574
Percentage mean variation	....	4.5	5.4	4.9	....	....	7.4	6.0	6.6
				Cement D					
		1 day	3 days	28 days			1 day	3 days	28 days
No. 1	10.9	346	475	503	49.0	110	2746	4715	6335
No. 2	10.9	413	574	597	50.0	107	2335	4419	5683
No. 3	10.9	348	437	545	47.2	106	2828	4466	6116
No. 4	11.0	313	423	479	49.0	110	2767	4422	5961
No. 5	10.8	375	459	486	49.5	114	2770	4596	6260
No. 6	10.8	350	471	569	48.6	110	2279	4051	5504
No. 7	10.7	368	462	576	51.0	110	2518	4129	6024
No. 8	10.7	390	461	542	49.0	110	3094	4875	6466
No. 9	10.8	398	499	606	53.3	111	2075	4030	5822
No. 10	10.7	377	481	517	49.5	109	2239	4122	5479
No. 11	10.8	384	439	534	50.7	109	2843	4525	5919
No. 12	10.7	....	504	562	50.0	108	....	4111	5654
No. 13	11.1	339	445	463	50.0	104	2628	4412	5840
No. 14	11.0	330	515	570	52.8	110	2295	4115	6035
No. 15	10.8	361	448	506	50.0	102	2655	4392	5675
Avg.	10.8	**364**	**473**	537	50.0	109	2577	**4359**	**5919**
Percentage mean variation	....	**6.2**	**5.8**	6.5	....	....	**9.5**	**4.3**	**3.9**

TABLE II.—FLEXURAL AND COMPRESSIVE STRENGTHS OF MORTAR PRISMS.

Laboratory	Mortar Prisms—1:2.75 Graded Ottowa Sand by Weight					Compressive Strength 2-in. Modified Cubes from Mortar Prisms, psi.		
	Mixing Water, per cent	Flow, per cent	Modulus of Rupture, psi.					
			3 days	7 days	28 days	3 days	7 days	28 days
			CEMENT A					
No. 1	50.0	109	470	720	980	....	....	....
No. 2	52.0	106	360	550	720	1560	2745	4390
No. 3	49.2	106	380	580	805	1805	3270	5140
No. 4	52.0	106	395	590	775	1785	3150	4705
No. 5	50.0	111	380	560	730	1700	2865	4765
No. 6	50.3	108	315	520	780	1285	2225	4035
No. 7	52.5	107	440	595	760	1660	2695	4135
No. 8	52.0	112	350[a]	495[a]	685[a]	1950	3215	4990
No. 9	53.5	102	425	595	740	1720	2915	4420
No. 10	51.0	111	355	525	710	1640	2940	4870
No. 11	52.1	110	415	605	....	1605	2565	3880
No. 12	50.0	108	370	535	700	1555	2685	3925
No. 13	51.4	101	440	610	740	1505	3125	4120
No. 14	52.8	104	390	615	860	1635	2810	4705
No. 15	51.0	101	375	565	720	1715	3050	4495
Avg.	51.3	107	393	583	771	1650	2875	4470
Percentage mean variation	....	....	8.2	6.1	6.9	6.7	7.7	7.4
			CEMENT B					
No. 1	49.0	108	435	735	885	....	....	....
No. 2	51.0	108	335	520	660	1360	2535	3815
No. 3	48.4	110	360	535	710	1560	2715	4115
No. 4	50.0	108	355	545	690	1540	2720	4115
No. 5	49.0	112	330	550	705	1610	2740	4210
No. 6	48.6	108	330	550	770	1210	2250	3360
No. 7	50.8	108	390	580	725	1465	2710	3810
No. 8	50.0	113	300[a]	435[a]	610[a]	1690	2700	4345
No. 9	52.0	104	330	515	675	1395	2600	4090
No. 10	50.0	107	335	500	725	1590	2820	4555
No. 11	49.3	109	395	585	745	1505	2720	3550
No. 12	49.0	108	320	550	705	1390	2590	3935
No. 13	50.0	102	425	590	700	1815	2740	3505
No. 14	52.1	108	350	590	770	1320	2395	4185
No. 15	51.0	106	350	540	710	1560	2985	4440
Avg.	50.0	108	360	563	728	1501	2659	4002
Percentage mean variation	....	....	7.5	6.7	5.2	8.3	4.9	6.7
			CEMENT C					
No. 1	49.0	107	465	645	930	....	....	....
No. 2	52.0	112	330	490	705	1450	2490	4265
No. 3	48.0	107	370	495	795	1725	2645	4680
No. 4	51.3	108	355	520	750	1590	2630	4485
No. 5	49.0	113	350	480	725	1625	2455	4445
No. 6	48.6	108	300	455	715	1205	1825	3325
No. 7	51.4	109	400	505	725	1470	2180	3735
No. 8	50.5	113	315[a]	435[a]	635[a]	1730	2690	4705
No. 9	52.0	104	335	480	715	1535	2460	4425
No. 10	50.0	111	325	470	735	1510	2590	4690
No. 11	51.0	110	420	525	780	1815	2445	4120
No. 12	48.5	107	355	490	720	1515	2365	4145
No. 13	50.0	106	385	515	780	1585	2420	3910
No. 14	51.4	100	340	520	840	1505	2530	4860
No. 15	51.0	101	325	445	705	1540	2600	4490
Avg.	50.2	108	361	503	759	1557	2459	4306
Percentage mean variation	....	....	9.3	6.1	6.2	6.7	5.1	7.6
			CEMENT D					
			1 day	3 days	28 days	1 day	3 days	28 days
No. 1	49.0	110	750	975	1155	....	....	....
No. 2	50.0	107	510	725	875	2375	3985	5260
No. 3	46.4	103	615	765	995	3065	4365	6110
No. 4	49.0	107	585	745	900	2665	3940	5470
No. 5	49.5	114	535	740	905	2755	4340	5690
No. 6	48.6	110	545	700	960	2320	3650	5165
No. 7	50.0	109	580	715	870	2210	3800	4790
No. 8	49.0	110	445[a]	600[a]	785[a]	2940	4330	6005
No. 9	50.7	103	565	740	885	2495	4070	5485
No. 10	49.5	111	490	685	925	2520	4390	6040
No. 11	50.7	109	595	710	825	2865	3800	4670
No. 12	50.0	108	....	725	840	....	3870	4915
No. 13	50.0	100	590	865	940	2580	4460	5520
No. 14	52.8	110	540	790	1035	2200	3905	5730
No. 15	50.0	102	545	755	970	2585	4220	5445
Avg.	49.7	108	573	761	933	2584	4075	5373
Percentage mean variation	....	....	7.5	6.8	6.9	7.8	4.3	6.7

[a] Not included in average and percentage mean variation because 12-in. span was used.

TABLE IIA.—DETAILS OF TESTS ON MORTAR PRISMS.

Laboratory	Size of Prism, in.	Flexural Strength Test Procedure[a]				Modified 2-in. Cubes Tests at Each Age on Each Round
		Testing Device Design	Maximum Stress Extreme Fiber, psi. per min.	Capacity of Dial Used, lb.	Least Division, lb.	
No. 1	2 by 2 by 10	Scholer	....	10 000	20	none
No. 2	2 by 2 by 11¼	PCA	150	2 000	5	2
No. 3	2 by 2 by 12	own	135	2 500	2.5	2
No. 4	2 by 2 by 12	PCA	150	10 000	20	3
No. 5	2 by 2 by 11¾	PCA	150	3 000	5	3
No. 6	2 by 2 by 8	PCA	675	12 000	10	2
No. 7	2 by 2 by 12	[b]	148	....	....	3
No. 8	2 by 2 by 14	own	210	....	5	3, 4, 6, or 9
No. 9	2 by 2 by 11¼	PCA	150	10 000	20	2
No 10	2 by 2 by 11¼	PCA	150–175	10 000	20	3
No. 11	2 by 2 by 10	own	150	3 000	5	2 capped
No. 12	2 by 2 by 11¼	own	150	10 000	20	3
No. 13	2 by 2 by 11¼	PCA	over 150	10 000	20	2 sawed to size
No. 14	2 by 2 by 11½	own	100	3 000	2.5	3
No. 15	2 by 2 by 11¼	own and PCA	1100	10 000	20	3

[a] All laboratories used a 6-in. span with center loading and made two tests on one prism at each age on each round except as follows:

Laboratory No. 8 used 12-in. span with third-point loading and made one test on a prism and tested two prisms at each age on each round for cements A, B, and D and laboratory No. 11 reported only one test value for each age on each round.

[b] Used flexure testing device attached to a briquet testing machine.

mum stress in the extreme fiber varying over quite a range between laboratories.

Eight of the laboratories used flexural testing devices constructed in accordance with a drawing furnished by the Research Laboratory of the Portland Cement Association. It uses a 6-in. testing span with center-loading which allows two tests on a 2 by 2 by 11¼-in. prism.

The other seven laboratories used devices which they already had on hand, all of which had a 6-in. test span with center-loading except laboratory No. 8 which used a 12-in. span with third-point loading. Table IIA gives details of prism size, testing devices, maximum stress in extreme fiber (psi. per min.), capacity and least division of the testing machine dial used by each laboratory.

4. *Compressive Strength of Modified 2-in. Mortar Cubes.*—The broken ends remaining after testing the mortar prisms in flexure were tested in compression as modified 2-in. cubes. The test method was essentially the same as A.S.T.M. Methods C 116 – 44[3] for concrete, except that the upper and lower bearing plates were 2 in. square and the rate of loading was as specified in Methods C 109. The number of tests made on each round by the different laboratories are given in Table IIA.

5. *Flexural Strength of Concrete.*—This test was made on concrete beam specimens having a cross-section of 6 by 6 in. except that laboratory No. 1 used a beam of 6 by 8-in. cross-section, and the beams were loaded at either the center-point or third-point of the test span. Details of beam size, test span, and loading are given in Table IIIA.

Each laboratory prepared concrete from local sand and coarse aggregate normally used as their laboratory standard aggregates. It was specified that the proportions be such as to produce a cement content of between 6 and 6.2 sacks per cu. yd., and a slump of 2 to 3 in. Mixing was done by the procedure normally used in each laboratory. Molding and curing of the specimens was in accordance with A.S.T.M. Method C 192 – 47 T.[4] Three specimens were made with each cement and one each was tested at 3, 7, and 28 days (1, 3, and 28 days for cement D). Most of the laboratories made two tests on each specimen. The number of tests made at each age and on each test round are listed in Table IIIA.

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[3] Standard Method of Test for Compressive Strength of Concrete Using Portions of Beams Broken in Flexure (Modified Cube Method) (C 116 – 44), 1946 Book of A.S.T.M. Standards, Part II, p. 485

6. *Compressive Strength of Concrete.*—The broken ends remaining after testing the concrete beams in flexure were tested in compression as modified cubes in accordance with A.S.T.M. Method C 116 – 44. The number of tests made at each age on each test round are given in Table III(*a*).

7. *Miscellaneous Tests and Data.*—Each laboratory was asked to make standard A.S.T.M. tests for setting time, autoclave expansion, Wagner specific surface, and air content of mortar on each cement. Each laboratory was also asked to make chemical analysis of each cement, but this was optional. All laboratories were asked to supply certain miscellaneous information concerning the various tests.

Each laboratory calibrated its 10-in. flow table using a special flow table calibration mixture furnished through the courtesy of the Cement Reference Laboratory. The flow tables were calibrated before starting the test program and then again upon completion of the test program in order to determine if there was any change in the flow table during the period of the test series. Complete instructions for the calibration procedure were furnished to each laboratory by Mr. J. R. Dwyer. The flow value assigned to the calibration mixture was 108 per cent. The flows obtained with the calibration mixture are given in Table X.

It should be pointed out that the calibration mixture is not yet a regular Standard Sample of the National Bureau of Standards and it was used on only an experimental basis in these cooperative tests.

Each laboratory was asked to furnish answers to a questionnaire on details of flow table construction, pedestal, and method of measuring spread of the mortar on the table and arriving at per cent flow. The answers to the questionnaire are not included in this report.

DISCUSSION OF RESULTS

The results for tensile strength and compressive strength of mortar, percentage of mixing water used and per cent flow are given in Table I.

The percentage mean variation values in Table I show the reproducibility of the tests between laboratories. A convenient way for making comparisons is to average all of the values for each test age of the cements to obtain the grand average percentage mean variations as follows:

Test Age, Days	Tensile Strength (Method C 190)				Compressive Strength (Method C 109)			
	Cement A	Cement B	Cement C	Cement D	Cement A	Cement B	Cement C	Cement D
1	...	...	...	6.2	...	...	...	9.5
3	4.2	6.0	4.5	5.8	6.8	9.4	7.4	4.3
7	3.6	5.1	5.4	...	5.3	7.4	6.0	...
28	4.0	4.6	4.9	6.5	6.8	5.6	6.6	3.9
Average	3.9	5.2	4.9	6.2	6.3	7.5	6.7	5.9
Grand average	5.1				6.6			

Laboratory No. 6 reported it does not use 2-in. cubes for testing cement and, therefore, its operators were not experienced with this test. Laboratory No. 10 also does not use 2-in. cubes for testing cement because its molds are not approved by the Cement Reference Laboratory. The fairly large variation in

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[4] Tentative Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory (C 192 - 44 T), 1947 Supplement to Book of A.S.T.M. Standards, Part II, p. 272.

TABLE III.—TESTS ON CONCRETE.

Laboratory	Net Water-Cement Ratio, W/C, gal. per sack	Slump, in.	Cement Content, sack per cu. yd.	Air, per cent	Modulus of Rupture of Concrete Beams, psi.			Compressive Strength 6-in. Modified Cubes From Concrete Beams, psi.		
					3 days	7 days	28 days	3 days	7 days	28 days
CEMENT A										
No. 1	5.92	2.6	5.88	1.1	570	860	1025	2540	4195	5515
No. 2	4.92	2.9	6.10	1.0	575	765	870	3590	5700	7870
No. 3	5.88	2.1	6.09	...	345	530	620	2080	3150	4455
No. 4	5.77	2.5	6.09	1.3	690	860	940	3565	4660	5505
No. 5	4.60	2.7	6.14	2.3	530	715	855	3480	....	....
No. 6	4.77	2.8	6.17	...	460	610	670	3285	4780	6755
No. 7	4.87	2.9	6.13	1.3	525	610	825	3425	5320	6490
No. 8	5.30	2.1	6.10	1.7	625	735	860	4080	5925	7590
No 9	4.83	2.7	5.80	3.5	445	665	860	2370	4645	6800
No. 10	5.80	2.5	6.00	...	385	610	770	2210	3835	5125
No. 11	4.93	2.5	6.20	1.9	495	640	750	3950	5190	7050
No. 12	5.24	2.5	5.96	...	410	630	745	2600	3725	5620
No. 13	5.05	2.3	6.00	...	575	740	860	2970	4660	5680
No. 14	....	...	....	...	...	...	...	....	....	....
No. 15	5.70	2.9	6.00	...	455	690	815	3320	4980	6890
Avg.				1.8	506	690	819	3104	4674	6257
CEMENT B										
No. 1	5.92	2.8	5.79	5.2	525	685	910	2325	3610	4285
No. 2	4.67	2.7	6.00	5.2	500	675	780	2770	4235	5900
No. 3	5.82	2.2	6.06	5.6	350	485	565	1935	2840	3555
No. 4	5.57	2.7	6.14	3.8	645	795	925	3030	4005	4715
No. 5	4.32	2.5	6.03	6.1	475	645	740	2625	4195	5210
No. 6	4.77	3.8	6.17	...	365	495	550	2230	3440	4960
No. 7	4.63	3.0	6.11	...	465	580	690	3010	4580	5755
No. 8	4.77	2.5	6.18	7.6	595	685	765	3305	4920	5360
No. 9	4.22	2.5	5.84	6.0	420	690	745	2145	4055	6050
No. 10	5.30	2.8	6.00	6.0	320	560	685	1610	3040	4185
No 11	4.51	2.5	6.13	6.1	435	550	705	2730	4600	5895
No. 12	4.68	2.5	6.07	...	375	540	645	2140	3185	4400
No. 13	4.75	2.5	6.00	...	555	665	795	2920	4270	4930
No. 14	....	...	....	...	...	...	...	....	....	....
No. 15	4.90	2.9	6.00	...	400	585	670	2580	3820	5140
Avg.				5.5	459	617	726	2525	3914	5024
CEMENT C										
No. 1	5.84	2.3	5.90	1.0	555	745	1000	2570	3755	5195
No. 2	4.92	2.3	6.10	0.7	515	660	820	3310	4580	6765
No. 3	5.88	2.1	6.08	1.0	285	415	545	1705	2770	4460
No. 4	5.76	2.2	6.11	1.5	595	705	900	2955	3895	4840
No. 5	4.62	2.7	6.12	2.6	480	620	785	3365	4535	....
No. 6	4.77	3.5	6.17	...	415	530	650	3080	4210	6870
No. 7	4.79	2.5	6.16	1.1	430	565	670	3115	4780	5600
No. 8	5.30	2.0	6.10	1.7	570	680	825	3515	4965	6540
No. 9	4.41	2.5	5.88	3.2	435	625	820	2635	4435	6915
No. 10	5.80	2.7	6.00	...	330	490	770	1860	3235	5085
No. 11	4.93	2 2	6.22	2.0	420	505	705	3280	4585	6850
No. 12	5.04	2.3	5.99	...	385	525	700	2265	3585	5425
No. 13	5.20	2.5	6.00	...	545	670	870	2905	3935	5550
No. 14	....	...	....	...	...	...	...	....	....	....
No. 15	5.50	2.5	6.10	...	435	615	950	3090	4490	6610
Avg.				1.7	457	596	786	2832	4125	5900
CEMENT D										
					1 day	3 days	28 days	1 day	3 days	28 days
No. 1	6.02	2.2	5.83	1.7	635	850	985	2780	3655	4600
No. 2	4.88	2.7	6.10	1.4	575	765	925	4205	5780	7445
No. 3	5.88	2.9	6.07	2.0	400	515	685	2515	3835	4740
No. 4	5.81	2.7	6.06	2.0	645	795	950	3340	4280	5070
No. 5	4.60	2.1	6.08	3.3	585	700	830	3795	....	....
No. 6	4.77	3.0	6.17	...	475	630	720	3900	4975	6700
No. 7	4.89	2.8	6.10	2.2	475	620	765	3925	5105	6710
No. 8	5.30	2.5	6.03	2 9	625	830	905	4020	5945	7480
No. 9	4.49	2.5	5.88	3.3	575	825	925	3550	5970	7037
No. 10	5.80	2.7	6.00	...	440	590	740	2485	4020	5440
No. 11	4.93	2.5	6.17	2.8	555	700	815	3810	5010	7525
No. 12	5.10	2.6	5.95	...	...	635	720	...	4180	4980
No. 13	5.30	2.5	6.00	...	625	810	945	3550	4480	5605
No 14	....	...	....	...	...	...	...	....	....	....
No 15	5.50	3.0	6.00	...	500	720	915	3840	5430	6820
Avg.				2.4	547	713	845	3517	4820	6166

TABLE IIIA.—DETAILS OF TESTS ON CONCRETE BEAMS.

Laboratory	Size of Beam, in.	Flexural Strength Test Procedure				Modified 6-in. Cubes	
		Span, in.	Loading	A.S.T.M. Test Method	Tests at Each Age on Each Round	A.S.T.M. Test Method	Tests at Each Age on Each Round
No. 1	6 by 8 by 40	24	Center	....	2	C 116 - 44	2
No. 2	6 by 6 by 30	18	Center	....	2	C 116 - 44	2
No. 3	6 by 6 by 20	18	⅓ point	C 78 - 44	1	C 116 - 44	2
No. 4	6 by 6 by 40	18	Center	....	3	C 116 - 44	3
No. 5	6 by 6 by 32	18	⅓ point	C 78 - 44	2	C 116 - 44	3
No. 6	6 by 6 by 32	18	⅓ point	C 78 - 44	2	C 116 - 44	2
No. 7	6 by 6 by 30	18	⅓ point	C 78 - 44	2	C 116 - 44	2
No. 8	6 by 6 by 33	18	Center	....	2	C 116 - 44[a]	2[b]
No. 9	6 by 6 by 34½	18	⅓ point	C 78 - 44	2	C 116 - 44	2
No. 10	6 by 6 by 30	18	⅓ point	C 78 - 44	2	C 116 - 44	2
No. 11	6 by 6 by 30	18	⅓ point	C 78 - 44	2	C 116 - 44	2
No. 12	6 by 6 by 34	18	⅓ point	C 78 - 44	2	C 116 - 44	2
No. 13	6 by 6 by 30	18	⅓ point	C 78 - 44	1	C 116 - 44	1
No. 14	....		....	....	.	....	.
No. 15	6 by 6 by 20	18	⅓ point	C 78 - 44	1	C 116 - 44	2

[a] The 1-day specimens for cement D were not capped.
[b] Three tests on cement D at 1 day.

per cent mixing water used by the different laboratories for the 2-in. cube mortar may also be a contributing factor causing slightly higher percentage mean variation in the C 109 compressive strength test. There does not appear to be a consistent relationship between per cent mixing water and compressive strength.

The modulus of rupture of mortar prisms and the companion compressive strength results on modified 2-in. cubes are given in Table II. The grand average percentage mean variation between laboratories is 7.0 for modulus of rupture and 6.7 for compressive strength. These values are close to those for C 109 compressive strength in Table I.

The foregoing percentage mean variations in average strength between laboratories are probably not suitable criteria as to the relative reproducibility between laboratories of the several tests. The reason is because they are based on strength values which are the average of nine specimens (three each, tested at each age, on three different test rounds) while in routine testing, comparisons between laboratories are almost entirely on the basis of only three specimens tested at each age.

Measures of the relative reproducibility of the different mortar strength tests within a laboratory are the percentage mean variations in strength of three specimens from their average and between test rounds. A summary of these average percentage mean variations is as follows:

	Tensile Strength (Method C 190)	Compressive Strength (Method C 109)	Modulus of Rupture Mortar Prisms	Compressive Strength 2-in. Modified Cubes
Average percentage mean variation of three specimens from their average	3.5	2.2	2.5	2.4
Average percentage mean variation of three rounds of tests from their average	2.9	3.1	3.4	4.1

The percentage mean variations in strength of two concrete specimens from their average and between rounds of the concrete tests are given in Tables VI and IX.

Laboratory No. 15 made parallel flexural strength tests of mortar prisms,

TABLE VI.—PERCENTAGE MEAN VARIATIONS IN STRENGTH OF TWO CONCRETE SPECIMENS FROM THEIR AVERAGE.

Each value is the average percentage mean variation for three rounds of tests.

Laboratory	Concrete Beams Modulus of Rupture			Concrete 6-in. Modified Cubes Compressive Strength		
	3 days	7 days	28 days	3 days	7 days	28 days
CEMENT A						
No. 1	4.5	0.8	3.7	1.8	5.6	4.2
No. 2	3.0	4.0	2.6	1.3	1.1	1.2
No. 3	[a]	[a]	[a]	0.6	3.9	3.9
No. 4	2.4[b]	2.5[b]	1.4[b]	7.4[b]	5.8[b]	2.7[b]
No. 5	2.4	4.2	1.8	3.2[b]	...	...
No. 6	0.9	1.9	4.2	2.1	2.2	0.9
No. 7	0.6	4.4	2.7	6.6	1.3	5.3
No. 8	3.2	3.6	5.2	3.1	1.5	2.7
No. 9	2.5	1.9	2.3	1.5	2.6	2.3
No. 10	4.1	4.4	1.2	1.8	1.6	1.1
No. 11	1.3	3.6	5.8	2.1	2.1	3.4
No. 12	2.2	1.9	3.7	2.3	1.3	3.1
No. 13	[a]	[a]	[a]	[a]	[a]	[a]
No. 14	...	...	...	...	...	...
No. 15	[a]	[a]	[a]	2.7	2.1	2.8
Avg.	2.5	3.0	3.1	2.8	2.6	2.8
Grand Avg.	2.9			2.7		
CEMENT B						
No. 1	3.9	0.9	1.6	3.5	1.9	3.5
No. 2	1.5	3.1	2.6	2.1	1.1	0.4
No. 3	[a]	[a]	[a]	1.5	1.6	1.6
No. 4	3.4[b]	3.0[b]	2.2[b]	4.9[b]	6.4[b]	2.3[b]
No. 5	4.0	3.4	2.2	7.6[b]	5.3[b]	2.7[b]
No. 6	1.8	0.7	3.6	2.1	2.0	2.9
No. 7	0.9	3.3	5.0	1.4	0.9	2.8
No. 8	1.9	3.4	1.6	1.1	2.0	2.0
No. 9	3.4	2.6	1.6	3.4	0.9	1.0
No. 10	3.7	1.9	1.8	2.7	3.9	3.4
No. 11	1.9	1.8	2.7	2.0	2.1	2.5
No. 12	6.0	2.0	4.0	1.2	0.9	2.3
No. 13	[a]	[a]	[a]	[a]	[a]	[a]
No. 14	...	...	...	...	...	...
No. 15	[a]	[a]	[a]	2.3	1.4	0.0
Avg.	2.9	2.4	2.6	2.5	2.3	2.1
Grand Avg.	2.6			2.3		
CEMENT C						
No. 1	4.1	6.4	1.9	3.5	2.8	2.7
No. 2	5.2	3.7	1.6	1.4	1.9	0.8
No. 3	[a]	[a]	[a]	3.0	1.9	5.7
No. 4	3.2[b]	3.0[b]	2.7[b]	6.0[b]	5.0[b]	3.0[b]
No. 5	5.0	1.3	4.9	2.7[b]	8.3[b]	...
No. 6	4.0	3.5	3.1	1.8	3.3	3.0
No. 7	4.6	1.9	4.9	2.2	6.5	5.2
No. 8	2.6	2.3	4.2	2.6	0.8	2.2
No. 9	1.9	2.5	4.0	4.1	2.2	4.6
No. 10	2.4	3.2	1.1	3.3	0.9	5.9
No. 11	3.4	1.8	1.6	1.5	2.3	2.4
No. 12	2.1	1.0	3.2	2.8	1.0	3.2
No. 13	[a]	[a]	[a]	[a]	[a]	[a]
No. 14	...	...	...	...	...	...
No. 15	[a]	[a]	[a]	1.8	2.3	7.6
Avg.	3.5	2.8	3.0	2.8	3.0	3.8
Grand Avg.	3.1			3.2		

TABLE VI—*Continued*

Laboratory	Concrete Beams Modulus of Rupture			Concrete 6-in. Modified Cubes Compression Strength		
	1 day	3 days	28 days	1 day	3 days	28 days
CEMENT D						
No. 1	0.5	1.4	1.9	2.3	7.9	5.3
No. 2	3.3	1.7	2.5	0.8	1.2	0.9
No. 3	[a]	[a]	[a]	1.7	3.5	3.2
No. 4	4.0[b]	3.5[b]	1.6[b]	2.1[b]	5.9[b]	5.4[b]
No. 5	2.8	3.2	1.0	5.5[b]	...	...
No. 6	2.1	4.6	3.5	0.9	3.9	2.3
No. 7	4.0	2.1	3.5	1.9	4.8	1.6
No. 8	3.2	2.4	2.7	1.6[b]	1.3	2.6
No. 9	1.2	3.8	4.7	1.4	1.0	...
No. 10	3.4	3.9	4.1	1.2	2.5	1.6
No. 11	3.6	3.9	3.4	3.0	5.3	0.9
No. 12	...	2.4	2.8	...	2.6	4.2
No. 13	[a]	[a]	[a]	[a]	[a]	[a]
No. 14	...	...	...	...	...	...
No. 15	[a]	[a]	[a]	1.1	2.0	1.3
Avg.	2.8	3.0	2.9	2.0	3.5	2.7
Grand Avg.	2.9			2.7		

[a] Only one specimen tested on each round.
[b] Tested three specimens on each round.

TABLE VIA.—AGGREGATES USED IN THE CONCRETE TESTS.

Laboratory	Fine Aggregate	Coarse Aggregate
No. 1	natural sand (0—No. 4)	crushed stone (No. 4 to 1¼ in.)
No. 2		gravel (No. 4 to 1½ in.)
No. 3		gravel (No. 4 to 1 in.)
No. 4		gravel[a] (No. 4 to 1½ in.)
No. 5		gravel (No. 4 to 1½ in.)
No. 6		gravel (No 4 to 1½ in.)
No. 7		gravel (No. 4 to 1½ in.)
No. 8		crushed stone (No. 4 to 1 in.)
No. 9		gravel (No. 4 to 1¼ in.)
No. 10	natural sand	crushed stone
No. 11	natural sand (0—No. 4)	gravel[b] (No. 4 to 1¼ in.)
No. 12		gravel (No. 4 to 1½ in.)
No. 13		crushed trap rock (No. 4 to 1½ in.)
No. 14	....	....
No. 15	natural sand (0—No. 4)	crushed stone (No. 4 to 1½ in.)

[a] 45 per cent crushed material.
[b] Contains crushed material.

using the testing device designed by the Portland Cement Assn. and a testing device of their own design. The results obtained with the two devices were in close agreement. The results given for this laboratory in Table II were obtained with the device of their own design. This laboratory found it convenient to use a rate of loading such that the rate of increase in extreme fiber stress was approximately 1100 psi. per min. Since this was very much higher than the specified 150 psi. per min., this laboratory made a few comparative tests in which duplicate specimens were made from the same batch of mortar and one was tested at a rate of 150 psi. per min., and the other was tested at a rate of 1160 psi. per min. The results of these tests are as follows:

Rate of Loading, psi. per min.	Age, days	Average Modulus of Rupture, psi.	Strength Ratio (150 psi. per min. loading = 100)
150	1	535	.....
1160	1	560	104.7
150	3	673	.....
1160	3	724	107.5
150	7	730	.....
1160	7	822	112.6

It will be noted that slightly higher strength values were obtained with the faster rate of loading.

The results for modulus of rupture of concrete beams and for compressive strength of concrete 6-in. modified cubes are given in Table III. Although the cement contents are quite uniform, there is a wide range in water-cement ratio and strength between laboratories for a given cement. Since each laboratory used its own aggregates in preparing the concrete, this illustrates the effect of different aggregates on the water-cement ratio and strength of concrete made with the same cement.

Laboratories Nos. 1 and 15 made parallel compressive strength tests on 6 by 12-in. cylinders prepared from the same batches of concrete as were the concrete beams. The compressive strength of the 6 by 12-in. cylinders were, in all cases, lower than the compressive strength of the concrete 6-in. modified cubes, as shown below:

Laboratory	Cement	Average Compressive Strength of 6-in. Modified Cubes Greater than for 6 by 12-in. Cylinders by Amount Shown, psi.			
		1 day	3 days	7 days	28 days
No. 1	A	...	...	1283	560
	B	...	...	589	331
	C	...	...	1012	937
	D	...	505	...	945
	Avg.	...	505	960	693
No. 15	A	...	890	780	550
	B	...	340	170	270
	C	...	760	820	250
	D	350	580	...	290
	Avg.	350	642	590	340

One of the main purposes of these cooperative tests was to develop data from which could be determined the comparative relationship of the tensile, compressive, and flexural strength of standard mortar to the flexural and compressive strength of concrete. Correlation coefficients were selected as the statistical criterion of this comparative relationship and they were calculated and adjusted as described by Mordecai Ezekiel.[5]

In calculating the correlation coefficients, the all-laboratory average strength of concrete at all ages was considered the dependent variable and the tensile, compressive, and flexural strength of mortar were the independent variables. With this procedure, only the results for the four test cements could be used which made it necessary to exclude the results on additional cements submitted by the laboratories.

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[5] "Methods of Correlation Analysis," Second Edition. John Wiley & Sons, Inc., New York, N. Y. (1947).

TABLE IX.—PERCENTAGE MEAN VARIATIONS IN STRENGTH OF THREE ROUNDS OF TESTS FROM THEIR AVERAGE.

Laboratory	Concrete Beams Modulus of Rupture			6-in. Modified Cubes Compressive Strength		
	3 days	7 days	28 days	3 days	7 days	28 days
CEMENT A						
No. 1	3.2	4.1	1.1	13.8	6.6	4.7
No. 2	2.6	1.7	2.6	2.5	5.0	0.6
No. 3	1.5	3.8	0.3	1.7	2.8	2.0
No. 4	0.7	1.1	0.5	6.6	1.1	2.0
No. 5	2.2	2.6	2.1	7.9	...	...
No. 6	1.4	1.9	2.7	1.6	5.1	2.3
No. 7	4.4	6.8	3.4	3.5	3.3	8.9
No. 8	3.7	4.8	3.7	7.1	3.5	3.4
No. 9	6.7	2.8	1.3	3.8	3.1	5.0
No. 10	1.3	2.5	1.1	3.5	2.5	1.0
No. 11	3.4	1.6	0.7	2.8	2.8	4.8
No. 12	5.3	3.7	4.3	5.7	6.8	3.2
No. 13	6.1	1.6	1.0	4.9	5.0	8.8
No. 14	...	...	...	...	...	...
No. 15	8.4	2.4	6.7	3.2	4.3	1.3
Avg.	3.6	3.0	2.3	4.9	4.0	3.7
Grand Avg.	3.0			4.2		
CEMENT B						
No. 1	11.9	3.6	1.3	7.6	3.3	6.8
No. 2	1.0	3.7	2.6	0.9	4.7	1.1
No. 3	5.2	3.1	2.1	7.8	4.2	4.1
No. 4	1.3	2.1	0.9	2.0	2.2	1.5
No. 5	3.9	2.1	1.6	2.9	6.3	6.0
No. 6	3.0	5.0	3.3	2.7	0.7	3.4
No. 7	6.4	1.2	1.7	2.7	5.0	1.8
No. 8	1.9	0.5	1.3	2.9	2.7	1.1
No. 9	4.4	1.8	1.8	9.4	3.6	1.6
No. 10	0.6	2.2	2.6	2.0	4.8	4.2
No. 11	3.1	1.8	3.0	4.1	3.4	3.0
No. 12	12.0	5.2	5.9	6.2	6.2	11.0
No. 13	1.5	4.3	0.4	2.1	7.3	0.5
No. 14	...	...	...	...	...	...
No. 15	6.3	9.4	5.2	5.5	11.0	1.4
Avg.	4.5	3.3	2.4	4.2	4.7	3.4
Grand Avg.	3.4			4.1		
CEMENT C						
No. 1	5.7	2.6	1.0	9.9	3.1	7.5
No. 2	4.9	2.5	2.8	1.8	1.6	2.5
No. 3	2.3	6.4	10.1	4.4	3.7	8.5
No. 4	1.4	2.1	1.3	2.1	3.2	3.5
No. 5	3.8	1.1	4.1	8.1	11.2	...
No. 6	3.2	4.4	1.3	3.0	5.9	2.0
No. 7	0.8	3.5	5.8	3.8	1.6	2.5
No. 8	3.5	3.9	5.9	3.2	3.2	5.2
No. 9	7.0	4.8	0.8	5.3	10.2	1.5
No. 10	2.4	3.1	1.6	2.1	1.7	0.8
No. 11	4.0	5.0	4.6	4.8	2.1	2.7
No. 12	5.2	4.4	1.9	9.1	0.9	6.4
No. 13	4.6	0.7	4.2	2.3	3.4	9.0
No. 14	...	...	...	...	...	...
No. 15	7.3	5.1	5.8	2.5	4.2	1.7
Avg.	4.0	3.5	3.7	4.5	4.0	4.1
Grand Avg.	3.7			4.2		

TABLE IX—*Continued*

Laboratory	Concrete Beams Modulus of Rupture			6-in. Modified Cubes Compressive Strength		
	1 day	3 days	28 days	1 day	3 days	28 days
CEMENT D						
No. 1	2.9	2.7	0.2	5.9	6.9	5.3
No. 2	4.9	2.6	1.8	1.7	1.8	0.5
No. 3	5.4	1.6	1.0	8.3	2.2	1.8
No. 4	4.1	1.5	1.2	4.2	5.1	1.9
No. 5	5.7	2.6	0.8	5.5	...	...
No. 6	2.8	0.5	1.4	2.6	3.8	2.4
No. 7	2.5	4.6	2.4	2.5	2.0	0.2
No. 8	3.7	1.4	3.5	5.6	0.1	4.3
No 9	2.9	7.3	4.5	4.1	3.2	...
No. 10	2.1	1.8	2.0	2.2	1.5	1.7
No. 11	7.6	4.8	4.5	1.2	2.7	3.5
No. 12	...	9.7	6.3	...	9.6	5.4
No. 13	4.0	1.0	5.5	1.3	4.5	1.8
No. 14	...	...	...	...	...	...
No. 15	7.3	1.8	1.1	5.7	1.0	1.3
Avg.	4.3	3.1	2.6	3.9	3.4	2.5
Grand Avg	3.3			3.3		

TABLE X.—CALIBRATION OF 10-IN. FLOW TABLE WITH MIXTURE FURNISHED BY THE CEMENT REFERENCE LABORATORY.

Laboratory	Flow, per cent	
	At Start of Tests	At Finish of Tests
No. 1	97.8	96.9
No. 2	103.2	103.3
No. 3	108.0	108.0
No. 4	111.1	111.0
No. 5	108.4	107.5
No. 6	107.0	107.0
No 7	108.4	....
No. 8	113.0	114.5
No 9	104.2	106.6
No. 10	....	104.0
No. 11	106.0	....
No. 12	108.4	106.8
No. 13	108.8	105.3
No. 14	101.0	102.0
No. 15	98.0[a] 103.0[b]	....

[a] 25 drops in 15 sec. as specified in Method C 109.
[b] 25 drops in 30 sec.

The correlation coefficients are as follows:

CORRELATION COEFFICIENT BETWEEN MODULUS OF RUPTURE OF CONCRETE BEAMS AND:

Tensile Strength A.S.T.M. C 190 Briquets	Compressive Strength A.S.T.M. C 109 Cubes	Modulus of Rupture Mortar Prisms
0.919	0.949	0.903

CORRELATION COEFFICIENT BETWEEN COMPRESSIVE STRENGTH OF CONCRETE 6-IN. MODIFIED CUBES AND:

Tensile Strength A.S.T.M. C 190 Briquets	Compressive Strength A.S.T.M. C 109 Cubes	Modulus of Rupture Mortar Prisms
0.903	0.938	0.886

All of the correlation coefficients are positive and high, showing that the mortar and concrete tests are highly correlative. Those for the C 109 cubes are only slightly the highest, indicating slightly closer relationship to the modulus of rupture and compressive strength of concrete. The correlation coefficients for the modulus of rupture of the mortar prisms are the lowest of the three mortar tests, but they are still high enough to be considered satisfactory.

A measure of the efficiency of a mortar test is its power to discriminate between two cements having different strengths of concrete. Stated in another way, this means whether the mortar tests reveal the same relationship between the strength of two cements as does the concrete strengths.

A study was made of the data in Tables I, II, and III to determine the discriminating power of the different tests as disclosed by the results for cements A and C which have fairly wide differences in strength. The strengths for cement A at each test age were subtracted algebraically from companion strengths of cement C for each individual laboratory and the difference was expressed as a percentage of cement A strength. The percentage differences were then averaged algebraically and are as follows:

	Difference In Strength Between Cements A and C Expressed as a Percentage of Cement A Strength		
	3 days	7 days	28 days
MORTAR STRENGTH			
Tensile strength	−8.7	−9.6	+1.0
Compressive Strength (C 109)	−7.9	−10.3	−4.9
Modulus of rupture	−8.0	−13.6	−2.0
CONCRETE STRENGTH			
Modulus of rupture	−8.9	−13.6	−6.5
Compressive strength	−8.4	−12.1	−5.4

The indicated discriminating power is about the same for the five different kinds of tests at the age of three days. At seven days the percentage differences for the tensile strength and C 109 compressive strength tests are nearly equal and slightly below the values which the concrete tests show to be the difference between the two cements. At 28 days, the tensile strength test shows a plus value which means that higher strength was obtained for cement C than for cement A, but the concrete tests and other mortar tests show higher strength for cement A.

Since the foregoing determination of discriminating power of the different tests is for only two cements, the results cannot be considered as typical. However, it is of interest to note that for cements A and C the tensile strength test at the age of 28 days gives a false relationship between the two cements as compared to that given by the concrete tests.

Setting time, autoclave expansion, specific surface, and mortar air content of the cements are given in Table XI.

TABLE XI.—MISCELLANEOUS PHYSICAL TESTS. A.S.T.M. Methods.

Laboratory	Normal Consistency	Setting Time Gillmore		Autoclave Expansion	Specific Surface (Wagner)	Air Content, C 185
		Initial	Final			
CEMENT A						
No. 1	23.6	4:40	6:30	0.140	1755	8.3
No. 2	24.0	4:30	6:30	0.097	1760	....
No. 3	23.2	4:00	7:10	0.160	1790	7.2
No. 4	23.0	2:45	5:15	0.252	1795	....
No. 5	23.5	4:00	7:35	0.170	1755	6.1
No. 6	23.8	3:20	5:10	0.140	1782	....
No. 7	23.6	3:45	5:45	0.160	....	....
No. 8	22.8	2:35	4:25	0.160	1750	7.0
No. 9	....	....	....	....	....	....
No. 10	23.0	3:00	6:00	0.196	1730	....
No. 11	23.2	3:40	5:10	0.157	1956	10.5
No. 12	23.0	2:55	4:45	0.147	1758	....
No. 13	23.4	3:14	4:36	0.110	1780	10.3
No. 14	23.6	3:50	6:00	0.070	1840	7.0
No. 15	23.5	4:00	5:45	0.120	1650	7.8
Avg.	23.4	3:38	5:45	0.149	1777	8.0
CEMENT B						
No. 1	23.6	4:55	6:55	0.200	1700	18.6
No. 2	23.0	4:00	6:35	0.211	1720	20.5
No 3	23.2	3:50	7:20	0.250	1780	19.9
No. 4	23.3	3:15	5:45	0.226	1730	20.0
No. 5	23.0	4:50	6:20	0.270	1745	19.3
No. 6	24.0	4:05	5:40	0.230	1725	16.7
No. 7	23.6	3:30	5:45	0.250	....	17.2
No. 8	23.4	3:40	7:00	0.210	1980	20.2
No. 9	....	....	....	....	....	....
No. 10	23.0	3:30	6:45	0.314	1691	....
No. 11	23.0	4:25	6:35	0.272	1837	18.2
No. 12	23.5	2:30	4:55	0.192	1840	18.5
No. 13	23.8	2:55	4:50	0.150	1740	17.8
No. 14	24.0	4:00	9:00	0.148	1760	18.6
No. 15	24.0	4:25	6:00	0.190	1570	20.5
Avg.	23.5	3:51	6:23	0.222	1755	18.9
CEMENT C						
No. 1	25.0	4:30	6:50	0.040	1870	5.5
No. 2	27.0	4:30	6:30	0.040	1980	....
No. 3	25.6	3:40	7:00	0.050	2020	6.5
No. 4	27.5	4:30	6:35	0.044	1985	....
No. 5	25.0	4:40	5:55	0.040	2035	5.7
No. 6	25.5	3:45	5:05	0.040	2015	....
No. 7	25.2	3:00	5:30	0.020	....	....
No. 8	24.2	3:40	4:45	0.050	1760	4.6
No. 9	....	....	....	....	....	....
No. 10	24.0	3:30	6:30	0.052	1872	....
No. 11	25.8	4:25	6:20	0.065	2177	8.4
No. 12	25.0	3:00	5:10	0.037	1850	....
No. 13	27.0	4:09	5:24	0.110	1930	10.0
No. 14	25.2	3:40	6:50	0.052	1950	5.8
No. 15	24.5	4:00	6:25	0.040	1870	7.4
Avg.	25.5	3:52	6:03	0.049	1947	6.7
CEMENT D						
No. 1	26.6	4:45	6:05	−0.055	2745	9.1
No. 2	26.5	4:10	6:00	−0.063	2620	....
No. 3	26.4	3:15	6:45	−0.040	2710	11.0
No. 4	27.0	3:00	4:15	−0.053	2805	....
No. 5	26.0	3:30	5:10	−0.050	2605	11.6
No. 6	26.0	3:00	4:25	−0.050	2655	....
No. 7	25.4	3:00	5:00	−0.060	....	....
No. 8	25.0	2:45	4:15	−0.050	2740	11.7
No. 9	....	....	....	....	....	....
No. 10	25.0	3:15	5:45	−0.056	2705	....
No. 11	25.6	3:15	5:45	−0.044	2661	10.8
No. 12	25.5	2:25	3:55	−0.060	2682	....
No. 13	27.2	3:04	5:06	+0.140[a]	2600	12.0
No. 14	27.2	3:30	8:00	−0.038	2770	10.5
No. 15	26.0	3:30	5:00	−0.050	2440	11.1
Avg.	26.1	3:19	5:23	−0.051	2672	11.0

[a] Omitted from average.

CONCLUSIONS

The following conclusions appear to be warranted from a study of the results of this cooperative investigation:

1. The test results for flexural strength of mortar prisms used in this investigation, and with which the majority of the laboratories did not have previous experience, showed the following:

(*a*) Reproducibility within a laboratory, based on percentage mean variation in strength of three specimens from their average and between test rounds was about equal to the tensile strength and C 109 compressive strength.

(*b*) Reproducibility between laboratories was slightly poorer than for tensile strength and C 109 compressive strength.

(*c*) There was not a consistent quantitative relationship between modulus of rupture of mortar prisms and of concrete beams. The former was the lower for cement A, B, and C but was slightly the higher for cement D. The differences were not large and were greatest at the age of three days.

2. The compressive strength of 2-in. modified cubes from portions of the mortar prisms broken in flexure showed the following:

(*a*) Reproducibility within a laboratory based on percentage mean variation in strength of three specimens from their average and between test rounds was about the same as for tensile strength and C 109 compressive strength.

(*b*) Reproducibility between laboratories was about the same as that of C 109 compressive strength.

(*c*) Compressive strength was about the same as the C 109 compressive strength, except it was generally lower than C 109 at 28 days.

3. The comparative relationship of the C 190 tensile strength, C 109 compressive strength and modulus of rupture of mortar to the modulus of rupture and compressive strength of concrete as shown by correlation coefficients is as follows:

(*a*) All three mortar tests have high and positive correlation coefficients which indicate close relationship with modulus of rupture and compressive strength of concrete.

(*b*) There is only a narrow spread between the correlation coefficients. The C 109 compressive strength has the highest correlation coefficient and the modulus of rupture of mortar prisms the lowest correlation coefficient.

4. Although it is outside the scope of this report, it is of interest to note the excellent reproducibility of the concrete tests within laboratories as shown by percentage mean variation in strength of two specimens from their average and between rounds of tests.

Acknowledgments:

The Working Committee on Strength extends thanks and appreciation to the laboratories that participated in this cooperative investigation and to the cement companies that furnished the four test cements.

Respectfully submitted on behalf of the Working Committee:

G. L. LINDSAY,
Chairman.

MEMBERS:
R. F. BLANKS
H. F. GONNERMAN
E. P. NEWHARD
BAILY TREMPER
C. E. WUERPEL

APPENDIX II

REPORT OF THE STUDY SPONSORED BY THE WORKING COMMITTEE ON SO_3 CONTENT

The effects of gypsum on the properties of portland cement have been discussed by William Lerch in a paper on "The Influence of Gypsum on the Hydration and Properties of Portland Cement Pastes," which was presented before the Society at the 1946 Annual Meeting.[1] The studies described in that paper indicated that, with an optimum amount of gypsum, portland cement will exhibit greatest strength, least shrinkage upon drying, and least expansion upon wetting.

The optimum amount of SO_3 for different cements varies, being higher for cements of high alkali content and for cements containing large amounts of calculated tricalcium aluminate. High fineness was also shown to increase the optimum amount of SO_3 for cements of high, or moderately high, tricalcium aluminate content. As a result of those data, both Federal and A.S.T.M. specifications for portland cement were amended to permit a 0.5 per cent greater maximum limit on SO_3 when the cement contained more than 8 per cent calculated tricalcium aluminate.

During his preliminary discussion, Mr. Lerch further suggested a performance test on finished cement that would show whether the cement contains the optimum amount of gypsum. Such a performance test would have a distinct advantage over arbitrary chemical limits in specifications. Committee C-1 later formed a new subcommittee, with the personnel as indicated below, to study further this subject.

H. S. Meissner, *Chairman*
H. K. Cook
H. F. Gonnerman
G. L. Lindsay
W. J. McCoy
Bailey Tremper
G. C. Wilsnack

To proceed with its work, the subcommittee decided to check such a performance test on several cements, each containing various quantities of gypsum added in even increments. The optimum quantity of gypsum was to be defined by the several criteria described by Mr. Lerch:

1. Early heat of hydration as shown by rate of heat evolution.
2. Strength as registered in plastic mortar cubes.
3. Expansion of plastic mortar bars cured in water.
4. Contraction of plastic mortar bars subject to drying.

It was further agreed to conduct these tests upon cements representative of types I, II, III, and IV. Type V was considered to be fairly well represented by type IV cement. Both high- and low-alkali cements were included in each type, making in all, eight cements for the program. Each of these was prepared with seven different amounts of natural gypsum to provide SO_3 content in 0.5 per cent increments from 1 to 4 per cent (except for type III cement which contained 2 to 5 per cent).

The cements were prepared by grinding clinker with low SO_3 content and also grinding a portion of the same clinker with added gypsum to provide a high SO_3 content. These two cements were then blended to produce the various steps of SO_3 content. In some cases it was necessary to add gypsum to the cement to obtain the correct amount of SO_3. Two cements were ground in plant mills under normal production conditions. The remainder were ground in a laboratory ball mill.

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 46, p. 1252 (1946).

All cements were ground to approximately 1900 specific surface except two (high early) which were prepared to a specific surface of about 2100 and 2600. The cements were prepared and blended by two laboratories, and portions of each cement were distributed to the other participants.

The laboratories of the six subcommittee members cooperated on the study, although each member laboratory did not perform all of the tests. The rates of heat liberation were determined by two laboratories only, as they alone possessed conduction calorimeters as described in the above-mentioned paper by Mr. Lerch. Briefly, the apparatus consists of a brass cup which is filled with freshly mixed cement paste. This cup rests upon a pedestal and is covered with a vacuum flask. The pedestal conducts the heat from the cup to a heat-dispersing water bath and, by means of resistance thermometers wound upon it, the rate of heat generation in the paste is measured and recorded.

Five laboratories made strength determinations, and all six conducted expansion-contraction tests. Five or more laboratories made the usual physical properties tests, but the chemical analyses were determined by one laboratory only. One laboratory made flexural strength tests upon the plastic mortar bars (expansion specimens) cured in water after the 90-day volume change readings had been completed. Tensile strength tests (briquets) were made by one laboratory on two of the cements. Measurements of air content in mortar (A.S.T.M. Method C 185 – 47 T)[2] were made by one laboratory on one SO_3 content for each cement.

Extraction or leach tests, as proposed by Mr. Lerch, were made by all six laboratories. The leach tests have the advantage over certain of the other tests in that they can be performed within 3 days and do not require elaborate equipment.

Five of the laboratories agreed to conduct freezing-and-thawing experiments after preliminary work had indicated the optimum SO_3 content for each cement. It was felt desirable to include SO_3 contents on each side of the optimum for the durability studies.

One of the laboratories determined sugar solubilities in the Merriman sugar solubility tests. One laboratory conducted a leaching test on a neat cement slab similar to the slab used in the Merriman sulfate test.

The subcommittee has rendered a lengthy progress report wherein are presented the details of the results thus far obtained in the various tests, together with a discussion of the apparent relative merits of the different criteria as applied to those results. The results of the following tests were reported:

Chemical analyses of the cements; calculated compound composition.
Extraction tests of neat and mortar specimens.
Merriman sugar solubilities.
Rate of heat liberation.
Expansion of mortar bars in water, up to 90 days.
Contraction of mortar bars in air, up to 90 days.
Leaching tests on slabs in the Merriman sulfate test.
Compressive strength of mortars up to 90 days.

It is evident from these data that, if advantage is to be taken of the improvement which optimum gypsum will afford, specifications must permit higher SO_3

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[2] 1947 Supplement to Book of A.S.T.M. Standards, Part II.

limits than presently allowed. Although recent changes permit the use of more gypsum with high C_3A cement, these amendments have not been liberal enough to allow the manufacturer full opportunity to use gypsum in the quantity that his particular clinker may require. Increases of 1 to 2 per cent in present limits are indicated. There is ample evidence in these tests that cements of greater volume constancy can be obtained by using an optimum amount of gypsum. Unless the optimum amount is greatly exceeded, there appears to be little danger of excessive expansion, which is apparently the only reason for maximum limits on SO_3.

The investigation is still in progress, with particular attention being devoted to the study of durability.

Respectfully submitted on behalf of the Working Committee,

H. S. MEISSNER,
Chairman.

REPORT OF COMMITTEE C-7
ON
LIME*

Committee C-7 on Lime held two meetings during the past year: the first in Detroit, Mich., on June 23, 1948, during the Annual Meeting of the Society, the second in St. Louis, Mo., on October 26, 1948. The committee now consists of 47 members, of whom 23 are classified as producers, 7 as consumers and 17 as general interest members.

It was voted by letter ballot to amend the by-laws on date of polling letter ballots by adding a new section under Article 8 which requires that all ballots will carry a date of polling not less than four weeks nor more than six weeks from date of initial mailing.

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following tenatives be approved for reference to letter ballot of the Society for adoption as standard, without revision:

Tentative Specifications for:

Normal Finishing Hydrated Lime (C 6 – 46 T),
Special Finishing Hydrated Lime (C 206 - 46 T),
Hydrated Lime for Masonry Purposes (C 207 – 46 T).

Tentative Methods of:

Physical Testing of Quicklime and Hydrated Lime (C 110 – 45 T).

REAFFIRMATION OF STANDARDS

The committee recommends that the following standards which have stood without revision for six years or more be reaffirmed and continued in their present status without change:

Standard Specifications for:

Quicklime for Structural Purposes (C 5 – 26),
Sand for Use in Plaster (C 35 – 39),
Quicklime and Hydrated Lime for Cooking of Rags in Paper Manufacture (C 45 – 25),
Quicklime for Sulfite Pulp Manufacture (C 46 – 27),
Hydrated Lime for Varnish Manufacture (C 47 – 27),
Quicklime and Hydrated Lime for Use in the Textile Industry (C 48 – 24),
Quicklime and Hydrated Lime for Silica Brick Manufacture (C 49 – 42),
Quicklime and Hydrated Lime for Water Treatment (C 53 – 39), and
Hydraulic Hydrated Lime for Structural Purposes (C 141 – 42).

Standard Methods of:

Sampling, Inspection, Packing, and Marking of Quicklime and Lime Products (C 50 – 27).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[1]

This report has been submitted to letter ballot of the committee, which consists of 47 members; 43 members returned their ballot, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

WALTER C. VOSS,
Chairman.

ROBERT S. BOYNTON,
Secretary.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

REPORT OF COMMITTEE C-8
ON
REFRACTORIES*

Committee C-8 on Refractories has held two meetings during the past year, the seventy-fourth in Conneaut Lake Park, Pa. on September 9, 1948, and the seventy-fifth in Chicago, Ill., on March 1 and 2, 1949.

The committee has lost two members by death, R. M. Bowman, Republic Steel Corp., a long-time member of the committee, and Louis A. Smith of Jones & Laughlin Steel Corp. who had been a member of the committee only a few years, but had done good service as chairman of Subcommittee XII on Carbon Refractories. The American Foundrymen's Society was dropped from membership. New members elected were: C. R. Austin, representing the Research Department, Koppers Co.; A. H. Couch of Libbey-Owens-Ford Glass Co., B. L. Dorsay, representing Jones & Laughlin Steel Corp., and C. A. Varall, representing the Department of Public Works, New York City. The committee now consists of 37 members, of whom 17 are classified as producers, 12 as consumers, and 8 as general interest members. There are 14 consulting members.

TENTATIVE REVISIONS OF STANDARDS

Standard Methods of Chemical Analysis of Refractory Materials (**C 18 - 45**).[1]—The committee recommends the following tentative revision of this standard:

Section 16 (*a*).—In line 3, change "3.0 g." to "1.0 g". This change decreases from 3.0 g. to 1.0 g. the amount of NH_4Cl to be added to 1.00 g. of sample for alkali determination.

Section 31 (*a*).—Change the sixth and seventh sentences to read: "To volatilize boron, wash down the sides of the dish with 25 ml. of absolute methyl alcohol saturated with dry HCl gas. Evaporate, add methyl alcohol solution, and evaporate again."

Delete Note 2. These changes are on the border line of being editorial, but do state specifically that absolute methyl alcohol and dry HCl gas shall be used, as the present description does not.

Standard Specifications for Refractories for Heavy Duty Stationary Boiler Service (**C 64 - 48**),[2] *Refractories for Incinerators* (**C 106 - 48**),[2] and *Refractories for Moderate Duty Stationary Boiler Service* (**C 153 - 48**).[2]—The committee recommends a tentative revision of each of these three specifications by changing the modulus of rupture requirement on low-duty fireclay brick of type G from "800 psi." to "600 psi." The change will apply to Section 6 (*g*) of Specifications C 64, Section 5 (*c*) of Specifications C 106, and Section 5 (*b*) of Specifications C 153. In each of these three specifications the requirement was originally set at 500 psi. In 1947, a tentative revision was adopted, changing this to 800 psi. No criticism or comment having been received during the year, the tentative revision was adopted as standard in 1948. Subsequent objections led Subcommittee VII on Specifications to reconsider the action and to recommend a lowering of the requirement to 600 psi.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] 1946 Book of A.S.T.M. Standards, Part II.

[2] 1948 Supplement to Book of A.S.T.M. Standards, Part II.

REVISION OF STANDARD, IMMEDIATE ADOPTION

Standard Method for Basic Procedure in Panel Spalling Test for Refractory Brick (**C 38 - 47**).[3]—The committee recommends the following revision for immediate adoption and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that this recommendation may be referred to letter ballot of the Society.

Section 6.—Change the third sentence to read as follows: "The spalling furnace shall be heated so as to reach 1830 F. in 20 to 25 min., 2190 F. in 50 to 55 min., 2370 F. in 75 to 80 min., and 2550 F. in 120 to 125 min." The rest of the paragraph is unaffected by the change of this one sentence, which gives a more precise specification regarding rate of heating than does the present description.

ADOPTION OF TENTATIVE REVISIONS AS STANDARD

Standard Method of Testing Refractory Brick Under Load at High Temperatures (**C 16 - 41**).—The committee recommends adoption as standard of the tentative revisions[2] pertaining to Sections 2 (*b*), 5 (*a*), 5 (*d*) and Table I.

Standard Definitions of Terms Relating to Refractories (**C 71 - 47**).—The committee recommends adoption as standard of the tentative revisions[2] covering 10 new definitions and 1 revision of an existing definition.

Standard Methods of Test for Cold Crushing Strength and Modulus of Rupture of Refractory Brick and Shapes (**C 133 - 39**).—The committee recommends the adoption as standard of the tentative revisions[2] pertaining to Sections 5 (*d*) and 9 (*c*) concerning tolerance in the rate of application of load, with the addition of the following sentence to the end of each of these paragraphs: "A tolerance of plus or minus 10 per cent shall be permitted in the rate of application of load with either the mechanical or hydraulic testing machine."

Standard Method of Panel Spalling Test for Fireclay Plastic Refractories (**C 180 - 47**).—The committee recommends adoption as standard of the tentative revisions[2] pertaining to Sections 3 (*a*), 3 (*c*), 3 (*d*), and 6 (*f*).

CONTINUATION OF TENTATIVE WITHOUT REVISION

Tentative Specifications for Castable Refractories for Boiler Furnaces and Incinerators (**C 213 - 47 T**).—The committee recommends continuation of this tentative without revision for another year.

REAFFIRMATION OF STANDARDS

The committee recommends reaffirmation of the following three standards which have been published for over six years without revision and are to be continued as such as no revisions are recommended at this time:

Standard Classification of:

Fireclay Refractories (C 27 - 41).

Standard Methods of Test for:

Size and Bulk Density of Refractory Brick (C 134 - 41), and

Warpage of Refractory Brick and Tile (C 154 - 41).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

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[3] 1947 Supplement to Book of A.S.T.M. Standards, Part II.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Industrial Survey (R. P. Stevens, chairman).—Surveys of current practice in the use of refractories in the lead industry and the plate and window glass industry are in preparation. Authors are being sought for surveys or revisions on copper, malleable iron, coke, and blast furnaces.

Subcommittee II on Research (R. E. Birch, chairman).—A revised list of research problems connected with tests of refractories is in preparation.

Subcommittee III on Tests (S. M. Phelps, chairman).—This subcommittee has made the recommendations on which Committee C-8 based the actions on methods of test given earlier in this report.

Section A on Load (L. J. Trostel, chairman) is doing experimental work on the load test at two laboratories, and has under consideration experimental work on fireclay stoppers.

Section B on Spalling (R. S. Bradley, chairman) has begun a study of the modifications that may be advisable in specifying a spalling test for semi-silica brick as distinct from other types of firebrick.

Section C on Temperature (J. L. Carruthers, chairman) has ready for distribution pyrometric test cones made of six standard samples prepared by the American Refractories Institute Fellowship at Mellon Institute, ranging from cone 20 to cone 38, together with material for making the cone plaque. Laboratories which have pyrometric cone equivalent (P.C.E.) furnaces are now being asked to run a series of tests, preferably with at least two different types of P.C.E. furnace. It is hoped that the results, when assembled, will show primarily the amount of variability that can be caused by different types of furnace, and secondarily, the range of difference between P.C.E. tests in different laboratories using the same type of furnace.

Work done by H. F. Smalley at the School of Ceramics, Rutgers University, under an Orton Foundation Fellowship, has shown that reproducible results are obtainable with the Denver Fireclay Co. furnace provided an automatic flow controller is used; otherwise the cones have a tendency to be bent by high-speed gases and give erratic results in this furnace.

Section E on Chemical Analysis (H. A. Heiligman, chairman).—Work reported last year has led to revision in the methods of removing boron and determining alkalies. The Section was asked to investigate the possibility of obtaining a more representative sample of raw chrome ore of refractory grade than the sample now included in the Bureau of Standards series.

Section F on Tests for Refractory Insulation (W. L. Stafford, chairman) has reviewed data accumulated through a period of several years concerning the advisability of adopting a panel shrinkage test in place of the present reheat shrinkage test for insulating firebrick. The conclusion is that the panel test gives no additional information on the probable service performance of insulating refractories and may possibly not give as much information as the present test. A panel test will, therefore, not be further considered.

The Section was asked to keep in mind the possible usefulness of a test to show the effect of a reducing atmosphere such as is used in annealing furnaces.

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[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

Section G on Porosity and Permanent Volume Change (S. M. Swain, chairman) has under consideration a change in the method of measuring brick in the Standard Method of Test for Reheat Change of Refractory Brick (C 113 – 46).

Section H on Tests for Mortars and Plastic and Castable Refractories (G. B. Remmey, chairman) has been asked to remove and revise Sections 9 (*b*), (*c*), and (*d*) of Tentative Specifications for Castable Refractories for Boiler Furnaces and Incinerators (C 213 – 47 T) as a new separate tentative method.

Section I on Carbon Monoxide Disintegration (H. M. Kraner, chairman) has assembled the results of a questionnaire on present practice together with a bibliography of the test and the physical chemistry connected therewith. A test method has been written and is now being revised.

Subcommittee IV on Heat Transfer (C. L. Norton, Jr., chairman).—Experimental work using the Standard Method of Test for Thermal Conductivity of Fireclay Refractories (C 202 – 47) brought out the fact that at least one brand of firebrick not only showed the property of changing in thermal conductivity with time and reaching a stable condition in which it could be satisfactorily measured but also showed the unexpected property of changing back to its original condition on cooling. Such behavior could cause considerable confusion and misleading results in the measurement of thermal conductivity at high temperatures, if unrecognized at the time measurements were made. This was a porous high-alumina refractory. Several other types of brick made from sintered and from fused alumina were tested and showed normal behavior.

Cooperation is requested with H. C. Dickinson, special investigator in the thermal conductivity section of the Bureau of Standards, in testing his special type of thermal conductivity apparatus, with which fairly rapid results can be obtained and checked.

Subcommittee VI on Nomenclature (W. S. Debenham, chairman) is cooperating with the Technical Committee on Refractories of the American Iron and Steel Institute, and with the Technical Advisory Committee of the American Refractories Institute, in assembling a larger glossary of terms concerning refractories than is now available. The committee has been requested to prepare definitions differentiating between refractory concrete and castable refractories.

Subcommittee VII on Specifications (J. D. Sullivan, chairman) is studying the Tentative Specifications for Ground Fire Clay as a Mortar for Laying-Up Fireclay Brick (C 105 – 47) to determine whether it should be broadened and whether uses other than as mortar for laying-up fireclay brick should be included in the one specification. This study will involve sieve analyses of various commercial clays. The committee reopened the question of the requirement on modulus of rupture of fireclay brick of type G for boiler and incinerator service, referred to earlier in this report.

Subcommittee IX on Classifications (L. C. Hewitt, chairman) has been working on the question of a separation of semi-silica brick as a distinct class of fireclay brick and was asked to consider also its classification in association with silica brick. Possible classifications of sillimanite brick and mullite brick are also being considered.

Subcommittee XI on Special Refractories (H. Wilson, chairman). Groundwork is being done on definitions, specifications, and test methods for a variety of types of special refractories before turning these matters over to the subcommittees most directly concerned.

Subcommittee XII on Carbon Refractories (E. B. Snyder, chairman) held its first meeting this year and defined its scope to include two classes of refractories: those which consist essentially of carbon, and those which contain both carbon (usually graphite) and ceramic ingredients.

Subcommittee XIII on Foreign Tests and Specifications (J. F. Kelly, chairman) has reviewed and advised upon proposed tests and specifications for refractories in the Union of South Africa. Similar material from Canada and Great Britain is being studied. The Council of Scientific and Industrial Research at Jamshedpur, India, has asked for advice on testing of refractories. A list of 26 national standardizing organizations has been assembled, and an attempt will be made to find which of these will be interested in the standardization of tests and specifications on refractories.

Subcommittee XIV on Semi-Silica Brick (G. B. Remmey, chairman).—This new subcommittee was authorized to look into the whole problem of semi-silica brick in order to lay the groundwork for further consideration of tests, specifications, definitions, and classifications.

This report was submitted to letter ballot of the committee consisting of 34 voting members; 32 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

R. B. SOSMAN,
Chairman.
R. S. BRADLEY,
Vice-Chairman.

W. R. Kerr,
Secretary.

REPORT OF COMMITTEE C-9

ON

CONCRETE AND CONCRETE AGGREGATES*

Committee C-9 on Concrete and Concrete Aggregates has completed a year of considerable activity As a result, it offers for consideration five new tentative methods and revisions in eleven standards and tentatives. It held three meetings during the year: one on June 24, 1948, during the Annual Meeting of the Society in Detroit, Mich., another in St. Louis, Mo., on October 29, 1948, and one in Chicago, Ill., on March 2, 1949.

Regulations Governing Committee C-9 have been revised in several respects during the year. These revisions have dealt principally with defining active participation in the work of the committee and with limitations on numbers of members. Up to the present the membership has been limited to 75. Until about three years ago that meant 75 individuals, whether personal members or representatives of corporate members. In 1946 the Regulations were revised to limit the membership to 75 voting members and to provide that any number of individual members with the same employer collectively command only one vote. This was done in view of the evidence of increased interest in the work of the committee. Further evidence in that direction has led to the revision, just adopted, to raise the limit to 100 voting members.

On February 25, 1949, the committee suffered the loss through death of an Honorary Member, Sanford E. Thompson. He had been a member since the committee was organized and served as its first chairman during the period 1914 to 1922.

The Sanford E. Thompson Award, given by the committee for a paper of outstanding merit on concrete and concrete aggregates presented before the Society, was named in honor of Mr. Thompson. His continued interest in the affairs of the committee was always demonstrated when Mr. Thompson presented that award to its recipient. It was evident that Sanford E. Thompson had studied the paper selected and other articles on the subject.

Sanford E. Thompson Award.—This year's Sanford E. Thompson Award, the eighth, will be made to Mr. Richard C. Mielenz, head of the Petrographic Laboratory, and Leslie P. Witte, Materials Engineer, both of the Bureau of Reclamation, Department of the Interior, for their paper on "Tests Used by the Bureau of Reclamation for Identifying Reactive Concrete Aggregates," published in the 1948 *Proceedings*.[1]

Honorary Membership.—In accordance with provisions in the committee's Regulations, Roy W. Crum and Harry J. Love were elected Honorary Members of Committee C-9. Both men have participated actively in the affairs of the committee for over twenty years, Mr.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27-July 1, 1949.

[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 48, p. 1071 (1948).

Crum since 1923 and Mr. Love since 1917, and both have made outstanding contributions to its work. Mr. Crum served as chairman of the committee during the period 1932 to 1938 and held numerous other offices. Mr. Love was chairman of the Finance Committee and served on the Executive Subcommittee for many years.

NEW TENTATIVES

The following five new methods of test, as appended hereto,[1a] are recommended for publication as tentative by the committee:

Tentative Method of Test for:

Bleeding of Concrete,
Air Content of Freshly Mixed Concrete by the Pressure Method,
Air-Entraining Admixtures for Concrete,
Comparing Concretes on the Basis of the Bond Developed with Reinforcing Steel, and
Soft Particles in Coarse Aggregates.

The new Method of Test for Soft Particles in Coarse Aggregates is under the joint jurisdiction of Committee D-4 on Road and Paving Materials and Committee C-9 and is subject to their approval.

REVISION OF TENTATIVE

Tentative Specifications for Waterproof Paper for Curing Concrete (**C 171 - 42 T**).[2]—The committee recommends that these specifications be simplified by deleting the detailed description of the test method for strength of paper and making reference to an A.S.T.M. standard now on the books. The revision recommended is as follows:

Sections 5 to 10.—Delete these sections and insert the following as a new Section 5:

5. *Tensile Strength Test.*—Tensile strength shall be determined in accordance with the Standard Method of Test for Tensile Breaking Strength of Paper and Paper Products (A.S.T.M. Designation: D 828).[3]

ADOPTION OF TENTATIVE AS STANDARD

Tentative Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory (**C 192 - 47 T**).[4]—The committee recommends that this method be approved for reference to letter ballot of the Society for adoption as standard with the following revisions:

Section 9.—Before the last sentence, add the following: "Where voids are left by the tamping rod, the sides of the molds shall be tapped to close the voids."

Section 10.—Change to read as follows:

> 10. (*a*) The ends of all compression test specimens that are not plane within 0.002 in. shall be capped. Capped surfaces shall not depart from a plane by more than 0.002 in. and shall be approximately at right angles to the axis of the specimens. The planeness of the cap shall be checked by means of a straightedge and feeler gage making a minimum of three measurements on different diameters. Caps shall be made as thin as practicable and shall not flow or fracture when the specimen is tested.
>
> (*b*) The test specimens may be capped with a thin layer of stiff, neat portland cement paste after the concrete has ceased settling in the molds, generally from 2 to 4 hr. or more after molding. The cap shall be formed by means of a plate glass not less than ¼ in. in thickness or a machined metal plate not less than ½ in. in thickness and having a minimum surface dimension at least 1 in. larger than the diameter of the mold. It shall be worked on the cement paste until its lower surface rests on top of the mold. The cement for capping shall be mixed to a stiff paste 2 to 4 hr. before it is to be used in order to avoid the tendency of the cap to shrink. Adhesion of the paste to the capping plate may be avoided by coating the plate with a thin coat of oil or grease.

[1a] These methods were accepted as tentative by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 3.

[2] 1946 Book of A.S.T.M. Standards, Part II.

[3] 1946 Book of A.S.T.M. Standards, Part III-B.

[4] 1947 Supplement to Book of A.S.T.M. Standards, Part II.

(*c*) Specimens not capped with neat-cement paste as described in Paragraph (*b*) for fresh concrete shall be capped before testing. For specimens to be tested within 18 hr. after capping, suitable mixtures of sulfur and granular materials may be used regardless of the expected ultimate strength of the specimens. Sulfur caps should be allowed to harden for at least 2 hr. before applying load. Specimens expected to have an ultimate strength below 5000 psi. may be capped with gypsum plaster having a compressive strength of 5000 psi. or greater when tested as 2-in. cubes and mixed to the same consistency used for capping. For specimens to be tested 18 hr. or more after capping, neat alumina cement[a] may also be used for capping. Neat portland cement caps may be used but they must be aged sufficiently so they will not flow or fracture under load (suggested time, three days or more).

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[a] Lumnite Cement has been found satisfactory for this purpose.

Section 12.—Change the first sentence to read as follows: "The cross-section of the flexure test specimens shall be not less than 6 by 6 in. for coarse aggregate 2 in. and under in nominal size."

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions in eight of its standards, as set forth below, and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these revisions may be referred to letter ballot of the Society. Revisions in the first four standards listed below are similar in nature in that they call for changes in the requirements and procedure for capping concrete specimens.

Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Field (**C 31 - 44**):[2]

Section 6.—Revise to read as indicated above for Section 10 in Method C 192.

Section 8.—Revise to read as indicated above for Section 12 in Tentative Method C 192.

Standard Methods of Securing, Preparing and Testing Specimens from Hardened Concrete for Compressive and Flexural Strengths (**C 42 - 44**):[2]

Section 7 (*c*).—Change to read as follows:

(*c*) *Capping*.—Before making the compression test, the ends of the specimen shall be capped in order to meet the requirements given in Section 10 (*a*) of the Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory (A.S.T.M. Designation: C 192) following the procedure outlined in Section 10 (*c*) of that method.

Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam With Third-Point Loading) (**C 78 - 44**):[2]

Section 4.—Change the third sentence to read as follows:

If full contact is not obtained between the specimen and the load-applying blocks and the supports, due to the surfaces of the specimens being out of plane, the surfaces of the specimen, where they are in contact with the blocks or supports, shall be capped to meet the requirements given in Section 10 (*a*) of the Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory (A.S.T.M. Designation: C 192) following the procedure outlined in Section 10 (*c*) of that method.

Standard Method of Test for Compressive Strength of Concrete Using Portions of Beams Broken in Flexure (**C 116 - 44**):[2]

Section 3 (*a*).—Change to read as follows:

3. (*a*) The top and bottom of the beam shall be capped to meet the requirements given in Section 10 (*a*) of the Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory (A.S.T.M. Designation: C 192) following the procedure outlined in Section 10 (*c*) of that method. The caps shall cover the full width of the beam and shall be of such length as to permit the adjustment of the bearing plates for the test so that the upper bearing plate may be placed directly over the lower bearing plate.

Standard Specifications for Concrete Aggregates (**C 33 - 46**).[2]—The following revisions in Table II are recommended to bring these specifications into conformity with those recommended by the

U. S. Department of Commerce in its Simplified Practice Recommendation R 163 - 48:

Table II.—Make the following correction in this table:

For the 1 in. to No. 4 size, change the required percentage passing the 1-in. sieve from "90 to 100" to "95 to 100."

For the 2 in. to 1 in. size, change the required percentage passing the 2-in. sieve from "90 to 100" to "95 to 100," and add a requirement of "0 to 5" percentage passing the ½ in.-sieve.

For the ½ in. to No. 4 size, add a requirement of "40 to 70" percentage passing the ⅜-in. sieve.

For the 1½ in. to ¾ in. size, add a requirement of "0 to 5" percentage passing the ⅜-in. sieve.

Add two new sizes, "3½ to 1½ in." and "2½ to 1½ in." graded as given in the accompanying Table I:

TABLE I.—GRADING REQUIREMENTS FOR CRUSHED STONE, GRAVEL, AND BLAST-FURNACE SLAG.

Designated Size	Percentages Passing Laboratory Sieves Having Square Openings						
	4 in.	3½ in.	3 in.	2½ in.	2 in.	1½ in.	¾ in.
3½ in. to 1½ in.	100	90 to 100	...	25 to 60	....	0 to 15	0 to 5
2½ in. to 1½ in.	...	....	100	90 to 100	35 to 70	0 to 15	0 to 5

The committee also recommends the following revisions in Standard Specifications C 33 to bring about better agreement between these specifications and the "Standard Specifications for Fine Aggregate for Portland Cement Concrete" (M 6 - 42) of the American Association of State Highway Officials:

Table I.—Change the recommended and maximum permissible limits on clay lumps from "1.0" and "1.5" to "0.5" and "1.0," respectively.

Note to Table I.—Add the following sentence: "Only one set of figures for percentage by weight should be included in any single specification."

Section 4.—Add a new Note 1 as follows and renumber the current notes accordingly:

NOTE 1.—The No. 8 and No. 30 sieves may be used in addition to those specified, if the engineer desires to further control the grading of the material.

Standard Method of Test for Compressive Strength of Molded Concrete Cylinders (**C 39 - 44**):[2]

Section 4 (b).—Add the following as the last sentence to this paragraph: "No adjustment shall be made in the controls of the testing machine while a specimen is yielding rapidly immediately before failure."

Standard Method of Test for Amount of Material Finer than No. 200 Sieve in Aggregates (**C 117 - 48**).[3]—This method is under the joint jurisdiction of Committee D-4 and Committee C-9. Both committees recommend the adoption of the following minor revision as a change from circular opening to square opening seives to bring this method in line with A.S.T.M. specifications which define aggregate sizes:

Section 3.—In the table under this section, change the heading for size designation from "Nominal Diameter of Largest Particle, in." to "Nominal Maximum Sieve Size." Also, in the sizes designated change "¼ in." to "No. 4."

Standard Method of Measuring Length of Drilled Concrete Cores (**C 174 - 44**):[2]

Section 2 (d).—To permit measuring cores of various diameters with equal accuracy, change this section to read as follows:

> (*d*) The calipering apparatus shall be so designed that it will be possible to make a length measurement at the center of the upper end of the specimen and at eight additional points spaced at equal intervals along the circumference of a circle whose center point coincides with that of the end area of the specimen and whose radius is not less than one-half or more than three-fourths of the radius of the specimen.

Section 5.—Since the present refinement of measurements is considered to be in excess of that required, it is recommended that this section be changed to read as follows:

> 5. The individual observations shall be recorded to the nearest 0.05 in., and the average of the nine measurements expressed to the nearest 0.10 in. shall be reported as the length of the concrete core.

TENTATIVE REVISION OF STANDARD

Standard Method of Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (**C 131 - 47**).[4]—This method is under the joint jurisdiction of Committees D-4 and C-9. The present method provides only for testing coarse aggregates up to 1½ in. in size. Because of the use of larger sizes, particularly in highway construction and for railroad ballast, the need for broadening the scope of test has been felt for some time and a tentative revision, providing for testing sizes up to 3 in., was recommended for publication in June, 1947. Cooperative laboratory investigations were carried out with the view of making the same conditions apply to coarser sizes as now exists with the present four gradings, that is, make it feasible to fix the same specification limits for all sizes to indicate a given quality. These studies indicate that a modification of the tentative revision submitted in 1947 will go much further toward the goal of providing approximately the same percentage of loss in the larger sizes as in the smaller sizes for the same quality of material. Both committees recommend the withdrawal of the tentative revisions published in 1947 and the acceptance of the following changes as a tentative revision of this method:

Section 3 (*b*).—Change to read as follows:

> (*b*) The abrasive charge, depending upon the grading of the test sample as described in Section 4, shall be as follows:

Grading	Number of Spheres	Weight of Charge, g.
A	12	5000 ± 25
B	11	4584 ± 25
C	8	3330 ± 20
D	6	2500 ± 15
E	12	5000 ± 25
F	12	5000 ± 25
G	12	5000 ± 25

Section 4.—Change to read as follows:

> 4. *Test Sample.*—The test sample shall consist of clean aggregate which has been dried in an oven at 105 to 110 C. (221 to 230 F.) to substantially constant weight and shall conform to one of the gradings shown in Table I (Note). The grading or gradings used shall be those most nearly representing the aggregate furnished for the work.
>
> NOTE.—It is recognized that different specification limits may be required for gradings E, F, and G than for A, B, C, and D. It is urged that investigations be conducted to determine the relationship, if any, which exists between results for these coarse gradings using the 10,000 g samples and the finer ones using the 5000 g samples.

Table I.—Change to read as shown in the accompanying Table II.

TABLE II.—GRADINGS OF TEST SAMPLES.

Sieve Size (Square Openings)		Weight and Grading of Test Sample, g.						
Passing	Retained On	A	B	C	D	E	F	G
3 in.	2½ in.	....	....	....	....	2500[a]	....	....
2½ in.	2 in.	....	....	....	....	2500[a]	....	....
2 in.	1½ in.	....	....	....	....	5000[a]	5000[a]	....
1½ in.	1 in.	1250	....	....	....	....	5000[a]	5000[a]
1 in.	¾ in.	1250	....	....	....	....	....	5000[a]
¾ in.	½ in.	1250	2500	....	....	....	....	....
½ in.	⅜ in.	1250	2500	....	....	....	....	....
⅜ in.	No. 3	....	....	2500	....	....	....	....
No. 3	No. 4	....	....	2500	....	....	....	....
No. 4	No. 8	....	....	....	5000	....	....	....

[a] Tolerance of plus or minus 2 per cent permitted.

Section 5.—Delete the first sentence and insert the following:

> 5. The test sample and the abrasive charge shall be placed in the Los Angeles abrasion testing machine and the machine rotated at a speed of from 30 to 33 rpm. For gradings A, B, C, and D the machine shall be rotated for 500 revolutions; for gradings E, F, and G it shall be rotated for 1000 revolutions.

WITHDRAWAL OF STANDARD

Standard Specifications for Sodium Silicate for Curing Concrete (**C 111 – 36**).[2]—The committee recommends that this standard be withdrawn since the use of sodium silicate has proved unsatisfactory for the curing of concrete.

REAFFIRMATION OF STANDARDS

The committee recommends that the following ten standards which have stood without revision for six or more years be reaffirmed as standard:

Standard Methods of Test for:[2]

Unit Weight of Aggregate (C 29 – 42),
Voids in Aggregate for Concrete (C 30 – 37),
Cement Content of Hardened Portland-Cement Concrete (C 85 – 42),
Flow of Portland-Cement Concrete by Use of the Flow Table (C 124 – 39),
Specific Gravity and Absorption of Coarse Aggregate (C 127 – 42),
Specific Gravity and Absorption of Fine Aggregate (C 128 – 42),
Clay Lumps in Aggregates (C 142 – 39),
Slump Test for Consistency of Portland-Cement Concrete (C 143 – 39), and
Volume Change of Cement Mortar and Concrete (C 157 – 43).

Standard Specifications for:[2]

Lightweight Aggregates for Concrete (C 130 – 42).

A number of these standards are currently being studied for possible revision in the near future. The Standard Method of Test for Cement Content for Hardened Portland-Cement Concrete (C 85 – 42) is being studied to determine the effect of reactive aggregates in combination with high-alkali cements on test results obtained, since there is a reasonable possibility that silica, soluble under the test procedure outlined, may be released in the reaction.

Revisions of the Standard Method of Test for Volume Change of Mortar and Concrete (C 157 – 43) are also being considered. A questionnaire has been distributed to various laboratories to determine current practices in measuring volume changes. Results of the survey will be used as a guide for future revisions.

Specifications for Lightweight Aggregates for Concrete (C 130 – 42) are being completely rewritten in the light of experience and laboratory test results recently published by the National Bureau of Standards, Bureau of Reclamation and others. The problem of preparing specifications for these materials is difficult; it involves developing new test methods since many now on the books are not applicable to lightweight aggregates.

CONTINUATION OF TENTATIVES WITHOUT REVISION

The committee recommends that the following four tentatives, which have stood without revision for two or more years be retained as tentative:

Tentative Method of Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (**C 88 – 46 T**).[2]—A questionnaire has been prepared for distribution to interested laboratories to develop information on details of the procedure followed in conducting this test, equipment used, etc. It is hoped that this survey may yield information helpful in further defining the procedure so that comparable test results may be obtained by various laboratories in tests of the same aggregates.

Tentative Method of Test for Water Retention Efficiency of Methods for Curing Concrete (**C 156 – 44 T**).[2]—This method is currently being reviewed. The consensus of the subcommittee, having it in charge, is that the method is not satisfactorily adaptable to testing curing compounds and, therefore, an independent method of test for performance of these materials will be prepared.

Tentative Method of Test for Air Content (Volumetric) of Freshly Mixed Concrete (**C 173 - 42 T**).[2]—Revision or rewriting of this method will be undertaken in the near future. The new Tentative Method of Test for Air Content of Freshly Mixed Concrete by the Pressure Method, whose publication as tentative is referred to earlier in this report, has much greater application in the field and laboratory than does this method. However, a revised volumetric type of test for air content is needed for concrete made with porous aggregates, such as slag and lightweight materials, where the pressure method is not applicable in its present stage of development.

Tentative Method of Test for Fundamental Transverse Frequency of Concrete Specimens for Calculating Modulus of Elasticity (Sonic Method) (**C 215 - 47 T**).[4]—Consideration is being given to suggestions for revisions to this method. However, action to be taken has not crystallized sufficiently to permit making any changes.

OTHER RECOMMENDATIONS

The committee has approved a definition of the term mineral aggregate which has been recommended to Committee E-8 on Nomenclature and Definitions as a replacement for the Tentative Definition of the Term Aggregate (C 58 - 28 T).[2] The approved definition is as follows:

> *Mineral Aggregate.*—An aggregation of pieces of gravel, crushed stone, slag, sand, or certain other materials of mineral composition graded to size.

The committee recommends that the following description of the term chert be published as information. It is expected that descriptions of other rock types will be prepared in the future and that these will be recommended for publication as tentative through the usual procedure of the Society.

> *Chert.*—Descriptively, chert is a fine-grained rock which is characterized by hardness (scratches glass, is not scratched by a knife blade), conchoidal fracture in dense varieties, the fracture becoming splintery in porous varieties, and a variety of colors. The dense varieties are very tough and are usually gray to black, or white to brown in color, less frequently green, red, or blue, and have a waxy to greasy luster. The porous varieties are usually lighter in color, most frequently being white or stained yellowish, brownish, or reddish, and have a chalky surface. Dense red and in some cases dense yellow, brown, or black chert is sometimes called "Jasper." Dense black and in some cases dense gray chert is sometimes called "Flint."
>
> Mineralogically, chert is composed of silica (SiO_2) in the form of chalcedony (microcrystalline fibrous quartz and interstitial or microfibrous opal), cryptocrystalline quartz, or opal, or combinations of any of these three. The determination of which form or forms of silica are present requires careful determination of optical properties, absolute specific gravity, or both.
>
> Geologically, chert occurs most frequently as nodules or bands in limestones and in sands and gravels derived from such rocks.

The recommendations appearing in this report have been approved by letter ballot of the committee, the results of which will be reported at the Annual Meeting.[5]

This report has been submitted to letter ballot of the committee, which consists of 75 voting members plus 6 honorary members having voting privileges; 65 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

K. B. WOODS,
Chairman.

STANTON WALKER,
Secretary.

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[5] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

REPORT OF COMMITTEE C-14
ON
GLASS AND GLASS PRODUCTS*

Committee C-14 on Glass and Glass Products held two meetings during the past year, at Bedford, Pa., October 8, 1948, and at Cincinnati, Ohio, April 26, 1949.

Mr. A. H. Wadman resigned the chairmanship of Committee C-14 in September, 1948, and Vice-Chairman E. Ward Tillotson took over this responsibility during the past year.

Revisions of the Tentative Definitions of Terms Relating to Glass and Glass Products (C 162 – 48 T) to include the complete glass glossary of some four hundred terms, compiled by the Committee on Classification, Nomenclature, and Glossary of the American Ceramic Society, have been approved by the committee and have been submitted to the Administrative Committee on Standards.[1]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Nomenclature and Definitions (H. H. Holscher, chairman) reviewed the glossary compiled by the American Ceramic Society as noted above and submitted it to Committee C-14 for approval.[1]

Subcommittee II on Chemical Analysis (G. E. F. Lundell, chairman).—D. C. Smith is serving as acting chairman of Subcommittee II until such time as Mr. Lundell is able to resume his work. The committee reported no activity over the past year. It was suggested that studies be carried out on the triple acetate method for the determination of sodium and on Hick's Method for the determination of potassium, that a study be made on borosilicate glass analysis, and that spectrographic methods receive some attention.

Subcommittee III on Chemical Properties (J. F. Greene, chairman).—Durability methods worked on in this committee have been passed on to Subcommittees VII and VII-A and have received further attention in these committees.

Subcommittee VI on Glass Construction Block and Tile (A. H. Baker, chairman).—Results of the letter ballot on the Proposed Tentative Methods of Sampling and Testing Structural Non-Load-Bearing Cellular Glass Blocks, presented for Committee C-14 action by the subcommittee, were so light and because of detailed comments accompanying the negative vote, the main committee asked the subcommittee to reconsider the proposed method. The subcommittee has since submitted a revised method to the main committee for letter ballot action.

Subcommittee VII on Glass Containers (K. C. Lyon, chairman) developed the Tentative Method of Sampling of Glass Containers that has been submitted to the Administrative Committee on Standards.[1]

Revisions of the Tentative Methods of Hydrostatic Pressure Test on Glass Containers (C 147 – 43), Polariscopic Examination of Glass Containers (C 148 –

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] See Editorial Note, p. 294.

43), and Thermal Shock Test on Glass Containers (C 149 – 43), will be considered in terms of the new Tentative Method of Sampling of Glass Containers.

Subcommittee VII-A on Pharmaceutical Containers (F. C. Flint, chairman).—The editorially revised Methods of Test for Resistance of Glass Containers to Chemical Attack, Tests B-A, P-W, and B-W were accepted by Committee C-14 and were recommended to the Administrative Committee on Standards.[1]

Subcommittee VIII on Flat Glass (D. E. Sharp, chairman) has been kept informed of the work of a "task group" of the Sectional Committee on Safety Glass functioning under the American Standards Association on an abrasion test for plastics which might be suitable for flat glass. A report from this group should be available shortly.

This report has been submitted to letter ballot of the committee which consists of 52 members; 20 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

F. V. TOOLEY,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee C-14 presented to the Society through the Administrative Committee on Standards the following recommendations:

New Tentative Method of:

Sampling Glass Containers (C 224 – 49 T),
Test for Resistance of Glass Containers to Chemical Attack (Test B-A) (C 225 – 49 T),
Test for Resistance of Glass Containers to Chemical Attack (Test B-W) (C 226 – 49 T), and
Test for Resistance of Glass Containers to Chemical Attack (Test P-W) (C 227 – 49 T).

Revision of Tentative Definitions of:

Terms Relating to Glass and Glass Products (C 162 – 48 T).

These recommendations were accepted by the Standards Committee on July 27, 1949, and the new and revised tentatives appear in the 1949 Book of A.S.T.M. Standards, Part 3.

REPORT OF COMMITTEE C-15

ON

MANUFACTURED MASONRY UNITS*

During the past year Committee C-15 on Manufactured Masonry Units held two meetings; one on June 23, 1948, at Detroit, Mich., and one on March 4, 1949, at Chicago, Ill. The officers for the present term are:

Chairman, J. W. Whittemore.
First Vice-Chairman, T. I. Coe.
Second Vice-Chairman, P. M. Woodworth.
Secretary, J. A. Lee.

The subcommittees of Committee C-15 have been quite active in the past year and have reviewed all tentatives and standards under their jurisdiction. The revisions recommended in this report have resulted from this review.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1948 Annual Meeting, Committee C-15 presented to the Society through the Administrative Committee on Standards the following recommendations:

Revisions of Tentative Specifications for:

Vitrified Clay Filter Block for Trickling Filters (C 159 - 45 T),
Structural Clay Facing Tile (C 212 - 46 T), and
Facing Brick (Solid Masonry Unit Made from Clay or Shale) (C 216 - 47 T).

Tentative Revision of Standard Methods of:

Sampling and Testing Structural Clay Tile (C 112 - 36), and
Sampling and Testing Brick (C 67 - 44).

Tentative Revision of Standard Specifications for:

Building Brick (Made from Clay or Shale) (C 62 - 44).

These recommendations were accepted by the Standards Committee on November 16, 1948, and the revised tentative specifications and tentative revisions appear in the 1948 Supplement to Book of A.S.T.M. Standards, Part II.

TENTATIVE REVISIONS OF STANDARDS

The committee recommends revisions of the following seven standards for publication as tentative revisions.

Standard Specifications for Building Brick (Made from Clay or Shale) (**C 62 - 44**):[1]

Section 2.—Add the following as a new Paragraph (*e*), relettering the subsequent paragraphs accordingly:

(*e*) *Waiver of Durability Requirements.*—If brick are intended for use where no frost action occurs, or if frost action occurs where the average annual precipitation is less than 20 in., unless otherwise specified, the requirements specified in Paragraph (*a*) for water absorption (5-hr. boiling) and for saturation coefficient shall be waived and a minimum average strength requirement of 2500 psi. shall apply.

Section 2 (*e*).—Reletter and change to read as follows:

(*f*) *Strength.*—When brick are required having strengths greater than prescribed in Paragraphs (*a*) or (*d*), the purchaser shall specify the desired minimum strength according to the classification given in Table II.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27-July 1, 1949.

[1] 1946 Book of A.S.T.M. Standards, Part II.

TABLE II.—CLASSIFICATION BY COMPRESSIVE STRENGTH.

Designation	Minimum Compressive Strength (brick flatwise), psi., gross area	
	Average of 5 Brick	Individual
2500 lb.	5200	2200
4500 lb.	4500	4000
8000 lb.	8000	7000

Standard Methods of Sampling and Testing Brick **(C 67 – 44):**[1]

New Sections.—Add the following new Sections 36 to 42, covering methods for measurement of size and warpage:

MEASUREMENT OF SIZE

36. *Apparatus.*—Either a 1-ft. steel rule, graduated in $\frac{1}{32}$-in. divisions or a brick gage or caliper having a scale ranging from 1 to 12 in. graduated in $\frac{1}{32}$-in. divisions and having parallel jaws, shall be used for measuring the individual brick. Ten brick shall be averaged to determine the average measurement.

37. *Test Specimen.*—Ten dry full-size brick shall be measured. These brick shall be representative of the shipment and shall include the extremes of color range and size as determined by visual inspection of the shipment. (The same samples may be used for determining efflorescence and other properties.)

38. *Individual Measurements of Length, Width, and Depth.*—The length shall be measured along both beds and along both faces from the mid-points of the edges bounding the ends. These four measurements shall be recorded to the nearest $\frac{1}{32}$ in. and the average recorded to the nearest $\frac{1}{64}$ in. as the length. The width shall be measured in like manner across both beds and both ends from the mid-points of the edges bounding the faces. These four measurements shall be recorded to the nearest $\frac{1}{32}$ in. and the average recorded to the nearest $\frac{1}{64}$ in. as the width. The depth shall be measured across both faces and both ends from the mid-points of the edges bounding the beds. These four measurements shall be recorded to the nearest $\frac{1}{32}$ in. and the average recorded to the nearest $\frac{1}{64}$ in. as the depth. Either the steel rule or the brick gage described in Section 36 may be used. Retests shall be made by the same method when required.

MEASUREMENT OF WARPAGE

39. *Apparatus.*—The apparatus shall consist of the following:

(*a*) Steel straightedge.

(*b*) Steel rule graduated from one end in 32nds of an inch or alternately a steel measuring wedge. A steel wedge 2.5 in. in length by 0.5 in. in width by 0.5 in. in thickness at one end and tapered, starting at a line 0.5 in. from one end, to zero thickness at the other end. The wedge shall be graduated in 32nds of an inch and numbered to show the thickness of the wedge between the base AB and the slope AC, Fig. 1.

(*c*) A flat surface of steel or glass not less than 12 by 12 in. in area and plane to 0.001 in.

40. *Sampling.*—The sample of 10 brick selected for determination of size shall be used.

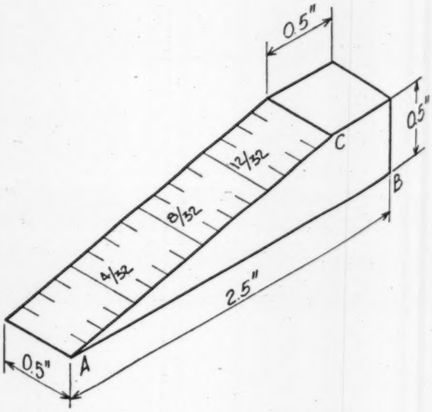

FIG. 1.—Measuring Wedge.

41. *Preparation of Samples.*—The specimens shall be tested as received except that any adhering dirt shall be removed by brushing.

42. (*a*) *Procedure.*—Where the warpage is concave, the straightedge shall be placed lengthwise or diagonally along the surface to be measured, selecting the location which gives the greatest departure from straightness. The maximum warpage as shown by the greatest distance of the brick surface from the edge of the straightedge should be selected and measured either by the steel rule or wedge. This distance shall be measured to the nearest $\frac{1}{32}$ in. and recorded as the concave warpage.

(*b*) When the warpage is convex, the brick shall be laid with the convex surface in contact with a plane surface and with the corners approximately equidistant from the plane. Measurements shall be taken from the plane surface to the four corners of the brick. An average of the four measurements shall be the convex warpage of the brick.

Standard Specifications for Sewer Brick (Made from Clay or Shale) (**C 32 – 42**):[1]

Table I.—Change the individual minimum compressive strength for grade *N A* from "2000 psi." to "2200 psi." Change the maximum percentages of water absorption by 5-hr. boiling from "20" to "22" for the average and from "24" to "25" for the individual brick.

Section 3 (a).—Change to read as follows:

> (*a*) *Size.*—The size of the brick shall be specified by the purchaser. The purchaser may specify one of the standard sizes of either building brick or paving brick.
>
> NOTE.—The purchaser should ascertain the size or sizes of brick available within the trade area of the project.

Standard Specifications for Structural Clay Load-Bearing Wall Tile (**C 34 – 41**):[1]

Section 6 (b).—Delete the first sentence and substitute the following: "Surfaces of tile for plaster-base finish shall be smooth, scored, combed, or roughened. When smooth, the tile shall be unglazed and the absorption shall be not less than 5 per cent nor more than 25 per cent."

Table I.—Change to read as follows:

TABLE I.—PHYSICAL REQUIREMENTS.

Grade	Maximum Water Absorption[a] by 1-hr. Boiling, per cent		Minimum Compressive Strength (Based on Gross Area),[b] psi.			
			End Construction Tile		Side Construction Tile	
	Average of five Tests	Individual	Average of five Tests	Individual	Average of five Tests	Individual
LB X....	16	19	1400	1000	700	500
LB.......	25	28	1000	700	700	500

[a] The range in percentage absorption for tile delivered to any one job shall be not more than 12.

[b] Gross area of a unit shall be determined by multiplying the horizontal face dimension of the unit as placed in the wall by its thickness.

Standard Specifications for Structural Clay Non-Load-Bearing Tile (**C 56 – 41**):[1]

Section 6 (b).—Change to read as recommended above for Section 6 (*b*) of Standard Specifications C 34 – 41.

Standard Specifications for Structural Clay Floor Tile (**C 57 – 39**):[1]

Section 6 (b).—Change to read as recommended above for Section 6 (*b*) of Standard Specifications C 34 – 41 with the addition of the following sentence to the end of this paragraph: "The surfaces of tile used in contact with concrete, where the thickness of the tile shell is used in the design section, shall be scored, combed, or roughened."

Standard Definitions of Terms Relating to Structural Clay Tile (**C 43 – 49**):

Plaster-Base Finish Tile.—Change the note under this definition to read: "Plaster-base finish tile may be smooth, scored, combed, or roughened."

Footnote 3.—Change the first sentence to read: "Smooth finish tile may be used in the wall either with or without paint or it may be plastered."

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the Tentative Definitions of Terms Relating to Structural Clay Tile (C 43 – 46 T)[1] be approved for reference to letter ballot of the Society for adoption as standard.

ADOPTION OF TENTATIVE REVISIONS AS STANDARD

The committee recommends that the tentative revisions[2] of the following standards be adopted as standard:

Standard Specifications for:

Building Brick (Made from Clay or Shale) (C 62 – 44), pertaining to "title," Section 2 (*f*), and the first sentence of Section 4.

Structural Clay Load-Bearing Wall Tile (C 34 – 41), pertaining to Sections 6 and 7,

Structural Clay Non-Load-Bearing Tile (C 56 – 41), pertaining to Sections 6 and 7, and

Structural Clay Floor Tile (C 57 – 39), pertaining to Sections 6 and 7.

EDITORIAL CHANGE

The committee recommends that the Tentative Specifications for Structural

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[2] 1948 Supplement to Book of A.S.T.M. Standards, Part II.

Clay Facing Tile (C 212 - 48 T) be editorially revised by inserting the word "Unit" between the words "Specified Dimension" in the headings of the two columns of Table IV.

CONTINUATION OF STANDARDS

The committee recommends that the following seven standards which have been published for six years or longer without revision are to be continued as such as no revisions are recommended at this time:

Standard Specifications for:[1]

Concrete Building Brick (C 55 - 37),
Sand-Lime Building Brick (C 73 - 39),
Hollow Load-Bearing Concrete Masonry Units (C 90 - 44),
Hollow Non-Load-Bearing Concrete Masonry Units (C 129 - 39),
Concrete Masonry Units for Construction of Catch Basins and Manholes (C 139 - 39),
Solid Load-Bearing Concrete Masonry Units (C 145 - 40).

Standard Methods of:[1]

Sampling and Testing Concrete Masonry Units (C 140 - 39).

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

This report has been submitted to letter ballot of the committee, which consists of 57 members; 37 members returned their ballots, of whom 36 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

J. W. WHITTEMORE,
Chairman.

J. A. LEE,
Secretary.

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[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee C-15 presented to the Society through the Administrative Committee on Standards the following recommendations:

Revision of Tentative Specifications for:

Structural Clay Facing Tile (C 212 - 48 T).

Tentative Revision of Standard Specifications for:

Structural Clay Non-Load-Bearing Tile (C 56 - 41), and
Structural Clay Floor Tile (C 57 - 39).

These recommendations were accepted by the Standards Committee on September 22, 1949, and the revised tentative and tentative revisions appear in the 1949 Book of A.S.T.M. Standards, Part 3.

REPORT OF COMMITTEE C-16
ON
THERMAL INSULATING MATERIALS*

Committee C-16 on Thermal Insulating Materials at its meeting, March 1, 1948, in Washington, D. C. considered a new set of by-laws changing the organization of the committee, which by-laws were adopted at the October 12, 1948, meeting in Atlantic City, N. J., and the reorganization became effective immediately.

The officers under the new organization are as follows:

Chairman, Ray Thomas.
First Vice-Chairman, B. A. Hollenbeck. (Thermal Group)
Second Vice-Chairman, H. W. Greider. (Non-Thermal Group)
Secretary, W. L. Scott.
Assistant Secretary, C. C. Callis.
Ass't. Secretary for Membership, E. C. Shuman.

The executive direction of the committee is vested in an Executive Subcommittee which consists of all the officers of the committee and one additional member at large. The Planning Subcommittee is composed of the chairman, two vice-chairmen, secretary, all subcommittee chairmen, and representatives from other societies and A.S.T.M. committees. The function of this group is to study and recommend on all general problems of the committee and on specific problems of the working subcommittees. The subcommittees are divided into two groups, one known as the Non-Thermal and the other as the Thermal Group, each under the direction of a vice-chairman.

Two meetings of Committee C-16 have been held, one at Atlantic City, N. J., on October 11 and 12, 1948, and one at Chicago, Ill., on February 28 and March 1, 1949. Both of these meetings were conducted according to the above plan and the results so far forecast, through uniform and combined effort, the expediting of achievements.

Two new subcommittees have been added, one on Membership and one on Significance of Tests.

The committee now consists of 56 voting members and 18 nonvoting members; 26 are classified as producers, 19 as consumers, and 11 as general interest members.

NEW TENTATIVE

The committee recommends that the Tentative Method of Test for Thermal Conductance and Heat Transmittance of Built-Up Sections by the Guarded Hot Box Method be accepted for publication as tentative as appended hereto.[1]

EDITORIAL CHANGES

The committee recommends that an editorial change be made in the following specifications:[2]

C 193 – 48
C 194 – 48
C 195 – 48 T
C 196 – 48
C 197 – 48

by inserting the following in Section 1 after the word "manufacturer" in the parenthesis, "on printed instructions supplied with the package of material."

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] This method was accepted as tentative by the Society and appears in the 1949 Book of A.S.T.M. Standards, Part 3.

[2] 1948 Supplement to Book of A.S.T.M. Standards, Part II.

The committee also recommends that the Standard Methods of Sampling and Mixing Thermal Insulating Cement (C 163 - 44)[3] be editorially revised by the addition of the same clause, referred to above, to the last sentence of Section 5 (*b*).

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee S-I on Block and Pipe Insulation (H. E. Lewis, chairman) has prepared test methods on water absorption of blocks, density of blocks, and density of pipe insulation which will be submitted as soon as the Editorial Subcommittee has given its approval.

Subcommittee S-II on Structural Insulation Board (S. M. Van Kirk, chairman) is considering revisions to test procedures of linear expansion and nail holding tests in the Standard Methods of Testing Structural Insulating Board Made from Vegetable Fibers (C 209 - 48). Consideration is also being given the proposed tests for evaluating insulation board as submitted by the Forest Products Laboratory.

Subcommittee S-III on Insulating Cement (J. E. Gaston, chairman) recommended the editorial changes of the five specifications and one method given earlier in this report. Consideration is being given to plasticity, adhesion, cohesion, hardness, and compression resistance as they apply to insulating cements.

Subcommittee S-IV on Blanket Insulation (R. L. Davis, chairman) prepared a definition of blanket or batt insulation for inclusion in the Standard Definitions of Terms Relating to Thermal Insulating Materials (C 168 - 48) which has been approved by the Editorial Subcommittee and submitted to Committee C-16 for letter ballot. A revision of the Standard Methods of Test for Thickness and Density of Blanket Type Thermal Insulating Materials (C 167 - 44), is being circulated for letter ballot within the subcommittee. The subcommittee is considering fire resistance tests for organic materials.

Subcommittee S-V on Loose Fill Insulation (J. F. White, chairman) is working on a method of determining the densities of loose fill insulation which has been accepted by the subcommittee, but requires several minor editorial revisions. A method for the determination of the thermal conductivity of loose fill insulations has been turned over to Subcommittee T-VI for inclusion in the Standard Method of Test for Thermal Conductivity of Materials by Means of the Guarded Hot Plate (C 177 - 45).

Subcommittee T-VI on Thermal Conductivity (E. R. Queer, chairman) prepared the proposed Tentative Method for Thermal Conductance and Heat Transmittance of Built-up Sections by the Guarded Hot Box Method, as appended to this report.[1] A revision of Standard Method C 177 has been drafted for determining the conductivity of loose fill insulations. This subcommittee is now drafting a tentative method of test for thermal *K* factor of pipe insulation.

Subcommittee T-VII on Special Thermal Properties (G. M. Rapp, chairman) is working on specific heat determinations and methods of determining emissivity and also methods of tests to determine effects of temperature and means of determining surface coefficients for heat loss curves.

Subcommittee S-VIII on Dimensional

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[3] 1946 Book of A.S.T.M. Standards, Part II.

[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

Standards (W. H. Zane, chairman) has continued the work on determination of field clearance between pipe and insulation. Consideration is being given to a special micrometer to measure the inside diameter of a half-round section of pipe insulation and simultaneously measure the half depth.

Subcommittee T-IX on Vapor Barriers for Insulation (R. H. Heilman, chairman) had accepted two methods of test (wet and dry) for determining water vapor permeability but is now holding in obeyance future work until the attitude of a task force group appointed by Committee E-1 on Methods of Testing is ascertained.

This report has been submitted to letter ballot of the committee, which consists of 56 members; 51 members returned their ballots, of whom 49 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

RAY THOMAS,
Chairman.

W. L. SCOTT,
Secretary.

REPORT OF COMMITTEE C-17
ON
ASBESTOS-CEMENT PRODUCTS*

Committee C-17 on Asbestos-Cement Products was organized on June 11,1946, in Washington, D. C., with subsequent meetings being held during the Spring Group Meetings of A.S.T.M. committees in 1947, 1948, and 1949. The major endeavor of the committee has been to draft specifications, including methods of test, covering asbestos cement roofing shingles, siding shingles, flat sheets, corrugated sheets, and pressure pipe.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Methods of Test, initially under the chairmanship of D. T. Colton, and now of Clyde R. Hutchcroft, was assigned the development of test methods. After several meetings and much labor, these were completed and submitted for inclusion in the product specifications.

Work on specifications for pressure pipe is in an advanced stage of progress in respect to the test method sections required.

A new subsection on significance of tests (J. H. Schiele, chairman), is presently working in this field.

Subcommittee II on Specifications (Miles V. Engelbach, chairman), was assigned the task of compiling complete specifications embracing the material submitted by Subcommittee I. Tentative specifications covering roofing shingles, siding shingles, flat sheets, and corrugated sheets, have been completed and were approved by Committee C-17. These will be submitted to the Administrative Committee on Standards.[1]

By-laws for the committee were submitted at the March, 1949 meeting, and were given preliminary approval and a letter ballot was authorized.

This report has been submitted to letter ballot of the committee, which consists of 32 voting members; 25 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

H. R. SNOKE,
Chairman.

CHESTER C. KELSEY,
Secretary.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] See Editorial Note at bottom of page.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee C-17 presented to the Society through the Administrative Committee on Standards the following recommendations:

New Tentative Specifications for:
Asbestos-Cement Flat Sheets (C 220 – 49 T), and
Asbestos-Cement Corrugated Sheets (C 221 – 49 T).

These recommendations were accepted by the Standards Committee on July 27, 1949.

On September 22, 1949, the following recommendations were accepted by the Standards Committee:

New Tentative Specifications for:
Asbestos-Cement Roofing Shingles (C 222 – 49 T), and
Asbestos-Cement Siding Shingles and Clapboards (C 223 – 49 T).

All of the new tentative specifications appear in the 1949 Book of A.S.T.M. Standards, Part 3.

REPORT OF COMMITTEE C-19
ON
STRUCTURAL SANDWICH CONSTRUCTIONS*

It has long been known that lightweight panels of great strength and stiffness could be achieved by the use of high-strength facing materials bonded to low density core materials, but it has only been in fairly recent years that such construction has become commercially important. The growing interest on the part of engineers, manufacturers, and builders in the advantages of structural sandwich construction has led to an increasing demand for information on methods of testing and evaluating the merits of various types of panels available and under development. In recognition of the demand for such information the Society organized on January 30 1948, Committee C-19 on Structural Sandwich Constructions. This committee has held a total of four meetings to date. Four technical subcommittees have been set up and are functioning as indicated later in this report. By-laws have been prepared and approved. The committee now consists of 61 members. The officers of the committee are as follows:

Chairman, A. G. H. Deitz
Vice-Chairman, D. G. Reid
Secretary, E. C. Hartmann
Membership Secretary, R. A. Biggs

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Mechanical Properties of Basic Materials (R. C. Platow, chairman) has been expanding its activities on what may legitimately be called the collating of available material necessary to establish a working premise for the activities of the subcommittee on the basic properties of materials used in sandwich construction. This approach is felt to be the primary problem that confronts this group.

The subcommittee is also gathering information on the properties of core materials with which the members are familiar and the methods of test which have been utilized in obtaining these figures.

For the purposes of expediting and assigning work, the subcommittee has subdivided into the following three sections:

Mechanical, S. E. Mautner, chairman
Physical, W. D. Eisenhauer, chairman
Electrical, C. B. Hemming, chairman

Subcommittee II on Mechanical Properties of Basic Sandwich Construction (E. W. Kuenzi, chairman).—Early meetings of this subcommittee involved discussions on the types of tests that were of most value to those interested in use of sandwich constructions in aircraft and in housing. The subcommittee was then divided into sections to consider testing methods for conducting tension tests, compression tests, shear tests, flexure tests, and tests of bond strength. Possible methods for all of these tests have been discussed. Tentative methods for submission to letter ballot of the committee are being prepared for the tension test, compression tests, and flexure tests.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1946.

The primary purpose of these tests will be to make available standard methods for determining properties and are not intended to be used as such for acceptance tests. A future development will probably be to devise acceptance tests based upon the methods which are to be devised for obtaining mechanical properties.

Subcommittee III on Permanence, Durability, and Simulated Service (D. G. Reid, chairman).—Due to the wide application of structural sandwich construction in various engineering fields, the decision was made to break down the activities of Subcommittee III on the basis of end use. This was accomplished by establishing sections on Building Construction, Transportation, Furniture, Packaging, Aircraft, and Miscellaneous. In addition a special section on Exposure Facilities was established for the purpose of assisting the work of the other sections by selecting and arranging for test sites. The various sections initiated studies and reviews of test methods now under development or in use by companies or agencies concerned with development and application of all types of sandwich construction.

Subcommittee IV on Nomenclature and Definitions (J. M. Stevens, chairman).—During the past year this subcommittee has prepared a list of twenty terms considered pertinent to the subject of structural sandwich constructions. A definition for structural sandwich construction has been accepted by a majority of the committee. Definitions for the remaining nineteen terms are currently being circularized among all members of the subcommittee for acceptance or rejection by letter ballot. Upon completion of this ballot these definitions will be referred to the full committee for final approval.

This report has been submitted to letter ballot of the committee, which consists of 48 voting members; 35 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

A. G. H. DIETZ,
Chairman.

E. C. HARTMANN,
Secretary.

REPORT OF COMMITTEE D-1
ON
PAINT, VARNISH, LACQUER, AND RELATED PRODUCTS*

Committee D-1 on Paint, Varnish, Lacquer, and Related Products held two meetings during the year: in Detroit, Mich., June 21 to 23, 1948, in connection with the Annual Meeting of the Society, and in Chicago, Ill., February 28 to March 2, 1949, in connection with the Spring Group Committee Meetings.

At the June, 1948, meeting, the following two papers were presented: "A New Color Difference Meter, Part 1, Design and Theory," by Richard S. Hunter, and "Part 2 Some Applications to Paints," by Francis Scofield; and "The Concept of Organic Coating Hardness," by M. H. Switzer.[1]

At the March, 1949, meeting, a panel discussion was presented on "Practical Aspects of the Testing of Paint and Varnish Products." Francis Scofield served as moderator and the panel was composed of C. C. Hartman, R. R. Bruhn, and W. G. Armstrong.

At this Annual Meeting, the following paper is being presented, "Surface Preparation and Repainting of Structural Iron and Steel," by Arnold J. Eickhoff.[2]

During the past year, a new Subcommittee on the Electrometric Testing of Paint Films has been organized under the chairmanship of William Shaw.

The D-1 Membership Committee, which was organized in 1946 to obtain new members for Committee D-1, particularly members engaged directly in the protective coating industry, has been active. The Membership Committee has succeeded in adding five new members to Committee D-1.

The D-1 Inter-committee Relations Committee which is composed of the D-1 representatives on other technical committees is continuing to follow closely the activities of other technical committees which may be of interest to Committee D-1.

Cooperative work with the Federation of Paint and Varnish Production Clubs has continued active during the year under the Joint Committee (Milton Glaser, chairman).

A Special Subcommittee on Location of Exposure Test Sites, under the chairmanship of H. A. Nelson, has been cooperating with the A.S.T.M. Advisory Committee on Corrosion in considering various types of test sites for exposure tests. These include not only industrial locations but also marine exposures, tropical locations, and rural test sites. The committee is studying the dirt collection conditions of certain sites by exposing painted panels.

On May 2, 1949, the Administrative Committee on Standards approved the recommendation submitted by Committee D-1 that the Tentative Specifications for Secondary Butyl Alcohol (D 1007 – 49 T) and the Tentative Method of Conducting Exterior Exposure Tests of Paints on Wood (D 1006 – 49 T) be accepted for publication as tentative. At the same time, the Administrative Committee on Standards also approved the recommendation submitted by Committee D-1 for a revision of Tentative Method of Test for Ester Value of Tricresyl Phosphate (D 268 - 46 T), which consists of changing "3 g." to "6 g." in Section 5 (*a*) and revising "30 min. on a hot plate at 200 C." to "2 hr. at 200 C. or until all oil disappears," in Section 5 (*b*).

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] ASTM Bulletin, No. 156, January, 1949, p. 67 (TP29).

[2] See p. 311.

On May 9, 1949, the Administrative Committee on Standards also approved the new Tentative Method for the Measurement of Dry Film Thickness of Paint, Varnish, Lacquer and Related Products (D 1005 – 49 T).

The three new tentatives are published in the 1949 Book of A.S.T.M. Standards, Part 4.

NEW TENTATIVES

The committee recommends for publication as tentative the following six new methods of test, as appended hereto:[3]

Methods of Test for:

Acetone Number of Heat-Bodied Drying Oils,
Bituminous Emulsions Intended for Use as Protective Coatings for Metal,
Night Visibility of Traffic Paints,
Aniline Point and Mixed Aniline Point of Hydrocarbon Solvents,
Total Nitrogen in Resins for Surface Coatings, and
Conducting Exterior Exposure Tests of Paints on Steel.

REVISIONS OF TENTATIVES

The committee recommends that the Tentative Method of Test for 60-deg. Specular Gloss of Paint Finishes (D 523 - 48 T) be revised, as appended hereto.[4]

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends the adoption as standard of the following four specifications and one method, without revision:

Tentative Specifications for:[5]

Pure Para Red Toner, Light (D 475 – 48 T),
Pure Toluidine Red Toner (D 656 – 48 T),
Copper Phthalocyanine Blue (D 963 – 48 T), and
Aluminum Pigments, Powder and Paste, for Paints (D 962 – 48 T).

Tentative Method of Test for:[5]

Phthalic Anhydride Content of Alkyd Resins and Resins Solutions (D 563 – 47 T).

TENTATIVE REVISION OF STANDARD

The committee recommends the following tentative revision of the Standard Methods of Testing Drying Oils (D 555 – 47):[6]

Section 2 (*i*).—Change to read as follows:

(*i*) *Acid Calcium Chloride Solution.*—Dissolve 600 g. of reagent grade $CaCl_2$ or 800 g. of reagent grade $CaCl_2 \cdot 2H_2O$ in a mixture of 80 ml. of HCl (sp. gr. 1.18) and 500 ml. of water. Dilute to 1 liter and mix. Filter if not clear.

New Section.—Add the following as a new Section 22:

22. *Set-to-Touch Time:* (*a*) *Apparatus and Materials.*—The apparatus and materials shall consist of the following:

Constant Temperature Room or Box, capable of maintaining a temperature of 25 ± 1 C., and a relative humidity of 25 to 75 per cent.

Glass Plates, at least 3 by 4 in. (roughening the surface slightly reduces the tendency of some oils to crawl).

Naphthenate Driers of known metal content.

(*b*) *Preparation of the Sample.*—Add drier in the concentration agreed upon by the interested parties (Note). Allow the prepared sample to stand at least 16 hr. before testing.

NOTE.—For many oils either 0.5 per cent lead and 0.03 per cent cobalt, or 0.06 per cent cobalt give satisfactory results, but other drier combinations are required by certain oils.

(*c*) *Procedure.*—Coat the sample of oil on the plate with a doctor blade or by other method, to give a wet film thickness of 0.0015 in. Place in a constant-temperature room in a horizontal position. A place should be selected with adequate air circulation, but without a perceptible draft, and with an illumination of approximately 25 foot candles. Test the film at intervals by touching lightly and gently with the finger and then touching a clean piece of glass. The end point is reached when the finger does not transfer any oil to the clean glass.

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[3] These methods were accepted as tentative by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 4.

[4] This revised method was accepted by the Society and appears in the 1949 Book of A.S.T.M. Standards, Part 4.

[5] 1948 Supplement to Book of A.S.T.M. Standards, Part II.

[6] 1947 Supplement to Book of A.S.T.M. Standards, Part II.

(*d*) *Report.*—Report the set-to-touch time in hours and tenths. If the intervals between tests are longer than 0.2 hr., report the result as being between the end point and the test immediately preceding it.

Revision of Standards, Immediate Adoption

The committee recommends for immediate adoption the following revisions in four standards and accordingly requests the necessary nine-tenths affirmative vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society:

Standard Specifications for Dry Bleached Shellac (D 207 – 35),[7] revise as follows:

Section 1.—In the note at the end of this section substitute "insoluble matter" for "matter insoluble in hot alcohol."

Section 2.—Delete the requirements for iodine number and change "Moisture, max., per cent, regular, 5.0, refined, 5.0" to read "Moisture, max., per cent, regular, 6.0, refined, 6.0." Insert the following new requirements: "Rosin, regular, none, refined, none; Copals, regular, none, refined, none."

Standard Specifications for Zinc Yellow (Zinc Chromate) (D 478 – 47)[6] revise by deleting the requirements for "combined water."

Standard Methods of Sampling and Testing Lacquer Solvents and Diluents, (D 268 – 48),[5] revise as follows:

Section 8.—In the first sentence, change "60°A.P.I. gasoline" to read "10° heptane having an aromatic content of not over 5 per cent." and add "and examine for turbidity" to the end of this sentence.

Standard Specifications for Tricresyl Phosphate (D 363 – 46),[7] revise by deleting the requirement for "free phenols" and changing the requirement for acidity from "0.005 per cent" to "0.01 per cent."

Editorial Changes

The committee recommends the following editorial changes in the Standard Method of Test for Spectral Characteristics and Color of Objects and Materials (D 307 – 44).[7]

Section 4 (*b*).—Change the note to read as follows in order to introduce a reference to the preparation of magnesium oxide standards in Method D 986:

Note.—See the Tentative Method of Preparation of a Magnesium Oxide Standard for Spectral Reflectivity (D 986 – 48 T) and the "Preparation and Colorimetric Properties of a Magnesium Oxide Reflectance Standard," *Letter Circular LC-547*, National Bureau of Standards, March, 1939.

Make the following changes in terms and symbols:

Tristimulus Designations.—Change to "*tristimulus values*" in Section 2 (*a*), (*b*), (*d*), and (*e*).

Tristimulus Specifications.—Change to "*tristimulus values*" in the column headings of Table III.

Spectral Irradiance.—Change the symbol, "*E*," for spectral irradiance to "*H*," in Sections 2 (*c*), (*g*), 13 (*a*), (*b*), (*c*), and in the column headings of Table I.

Trichromatic Coefficients.—Change to "chromaticity coordinates" in Sections 2 (*e*), 11, 12, 13 (*d*), and the column headings of Tables II and III.

Transmission.—Change to "transmittance" in Sections 2 (*f*), (*g*), (*p*), 10 (*a*), 11, 13 (*a*) (Note 1), (*d*) (Note 3), and 14 (*b*).

Apparent Reflectance (or Reflectivity).—Change to "*directional reflectance* or *reflectivity*" in Sections 2 (*j*), (*k*), (*n*), (*o*), (*p*), 7 (*c*), 10 (*a*), 11, 13 (*a*), (*d*), (Note 3), 14 (*b*), and the label of the ordinate in Fig. 1.

The committee recommends an editorial change in the following specifications for solvents and diluents so that the description of the heptane used in the water miscibility test will be changed to conform with the revision recommended in Section 8 of Methods D 268 – 48, given earlier in this report.

D 329 – 33
D 319 – 40
D 318 – 39
D 554 – 39
D 304 – 45
D 303 – 40
D 320 – 40
D 608 – 43
D 302 – 33
D 321 – 40
D 331 – 35
D 343 – 35
D 330 – 35
D 657 – 44
D 770 – 46
D 740 – 46

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[8]

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[7] 1946 Book of A.S.T.M. Standards, Part II.

[8] The letter ballot vote on these recommendations was favorable: the results of the vote are on record at A.S.T.M. Headquarters.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II on Drying Oils (Francis Scofield, chairman) prepared the new method of test for acetone number presented herewith and also recommended two tentative revisions for the method of test for drying oils presented in this report. The subcommittee is conducting cooperative work on hydroxyl number, break test and diene value. Work is also being done on a revision of the foots test.

Subcommittee III on Bituminous Emulsions (E. H. Berger, chairman) prepared the new methods of test for bituminous emulsions intended for use as protective coatings for metals. Work is being continued on two specifications for emulsions of the coal-tar and asphalt types which will be based almost entirely on performance requirements.

Subcommittee IV on Traffic Paint (W. G. Vannoy, chairman) prepared the new method of test for night visibility of traffic paints. Work is being continued on accelerated tests for durability of traffic paints and on specifications for glass beads for use in traffic paints. A study is also being made on accelerated tests for suspension.

Subcommittee V on Volatile Solvents for Organic Protective Coatings (M. B. Chittick, chairman) prepared the new methods of test for aniline and mixed aniline point presented in this report.[3] Methods for heptane number and kauributanol number have been completed and are being studied further. The subcommittee has under development methods of test for naphtha tolerance and diluting power of hydrocarbon solvents.

Subcommittee VI on Definitions (C. H. Rose, chairman) is preparing definitions for spar varnish, sealer, and size.

Subcommittee VII on Accelerated Tests (R. H. Sawyer, chairman) is continuing a study of a proposed revision of the Tentative Method of Preparation of Steel Panels for Testing Paint, Varnish, Lacquer, and Related Products (D 609 - 46 T). It is also continuing its studies on humidity testing and also on immersion testing. The subcommittee is working in cooperation with the Cleveland Paint and Varnish Production Club on the subject of the operation of light and water exposure units.

Subcommittee VIII on Chemical Analysis (C. Y. Hopkins, chairman) has under consideration revisions in the methods of analysis of zinc dust pigment, white pigments, iron oxide pigments, and chrome pigments. The subcommittee is also engaged in studying certain general methods of testing pigments such as for the determination of water-soluble matter and other general properties.

Subcommittee IX on Varnish (J. C. Weaver, chairman) recommended that Tentative Method D 563 be adopted as standard. The subcommittee is engaged in developing methods of test for drying and for the viscosity of transparent liquids. Work is also being done on the chemical resistance of dry varnish film and the evaluation of the exterior durability of varnish. The subcommittee is conducting cooperative tests on the use of pentaerythritol rosin ester for measuring the flexibility of varnishes.

Subcommittee X on Optical Properties (M. R. Paul, chairman) recommended the revision of Tentative Method D 523, as appended to this report.[4] The subcommittee is engaged in preparing a new method of test for the gloss evaluation of high-gloss finishes.

Subcommittee XI on Resins (C. T. Pickett, chairman) prepared the new method of test for the total nitrogen in resins for surface coatings. The subcommittee is conducting cooperative work on methods of testing resins, such as for the determination of total solids, melting point, and acid number of alkyd resins. Work is also being done on the iodine value of extracted fatty salts, the solvent tolerance of amino resins, the iodination method for the estimation of pure phenols, and the quantitative determination of chlorine in polyvinyls. Surveys are in progress on resin solubility, haze measurements, specific gravity, clarity and color of resins, and the classification and identification of phenol resins.

Subcommittee XII on Exterior Testing of Paints on Wood (Wayne Fuller, chairman) developed the new method for conducting exterior exposure tests of paints on wood, as previously mentioned in this report. The subcommittee has started work on the development of a test procedure for exterior exposure tests of trim paints on wood and on a form for recording test results.

Subcommittee XIII on Shellac (C. C. Hartman, chairman) is being set up as the American Committee in charge of the contacts with the ISO Committee on Shellac (No. 50) for which India holds the secretariat.

This subcommittee recommended the revision of Standard Specifications D 207, as given previously in this report. The subcommittee is working on a revision of the Standard Specifications for Shellac Varnishes (D 360 – 41) and the Standard Method for Sampling and Analysis of Shellac (D 29 – 40).

Subcommittee XIV on the Electrometric Testing of Paint Films (W. Shaw, chairman) is developing a method for conducting time-potential tests. This work will be followed by a study of the measurement and the significance of changes in the electrical resistance of paint films.

Subcommittee XV on Pigments (C. L. Crockett, chairman) recommended the revision of Standard Specifications D 478, given earlier in this report. It also recommended the adoption of four tentative specifications as standards. The subcommittee is drawing up new specifications for calcium carbonate and is also considering revisions in the Standard Specifications for Magnesium Silicate Pigment (D 605 – 42).

Subcommittee XVIII on Physical Properties (M. Euverard, chairman) developed the new method of test for dry film thickness. The subcommittee is engaged in work on the measurement of thickness of thin paint films and is also studying methods of preparing uniform films. Work is being continued on the development of a method of measuring the consistency of paste, the hardness of paint films, and the chalk resistance of pigments. Studies are also being made on the oil absorption and specific gravity of pigments and on the adhesion of paint films. A study of method of tests for determining the permeability of paint films is being undertaken.

Subcommittee XXV on Cellulosic Coatings and Related Products (F. H. Lang, chairman) prepared the new specifications for secondary butyl alcohol and a revision of the Tentative Method of test for the Ester Value of Tricresyl Phosphate (D 268 – 46 T). This subcommittee also recommended a revision of the Standard Methods of Sampling and Testing Lacquer Solvents and Diluents (D 268 – 46) and the Standard Specifications for Tricresyl Phosphate (D 363 – 46).

A new method for distillation range of lacquer solvents and diluents will be presented to the Society after the June meeting.[9]

Subcommittee XXIX on Painting of Metals (A. J. Eickhoff, chairman) recommended a new procedure for the field testing of paint coatings on steel. The scope of this subcommittee's work was recently enlarged to include metals other than steel.

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[9] See Editorial Note, p. 310.

This report has been submitted to letter ballot vote of the committee, which consists of 334 voting members; 181 members returned their ballots, of whom 119 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

W. T. PEARCE,
Chairman.

C. H. ROSE,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-1 presented to the Society through the Administrative Committee on Standards the recommendation that the Method of Test for Distillation Range of Lacquer Solvents and Diluents be accepted for publication as tentative. This recommendation was accepted by the Standards Committee on September 22, 1949, and the new tentative method appears in the 1949 Book of A.S.T.M. Standards, Parts 4 and 5, bearing the designation D 1078 – 49 T.

APPENDIX

THE SURFACE PREPARATION AND REPAINTING OF STRUCTURAL IRON AND STEEL

Report of a Study Conducted by Subcommittee XXIX on The Painting of Metals of A.S.T.M. Committee D-1

By Arnold J. Eickhoff[1]

This report is concerned with some of the factors involved in the preservation of iron and steel. It should be emphasized that the several conclusions reached herein are based on a statistical analysis of the test data. Some opinions are included as not having been drawn directly from a statistical interpretation of the data—such cases are so identified; for example, at what degree of corrosion is repainting desirable?

This is a final report of the work outlined in the Report on the Evaluation of Surface Treatment of Steel Prior to Painting presented in 1947.[2] As stated in this previous report, most metal protective paint studies reported in the literature have been concerned with the preparation and painting of new steel, unweathered steel, partially corroded steel, or steel cleaned by various mechanical means. This report is concerned with the repainting of painted, weathered steel surfaces.

The following questions, all of considerable practical interest, were studied in this investigation:

1. The maximum degree of corrosion permissible before repainting is necessary in order that economical protection can be maintained.
2. Comparison of three chemical pretreatments. All these are of the so-called cold type and are not to be confused with the hot pretreatments used on fabricated articles such as automobile bodies and refrigerators.
3. Comparison of paint performance over various surface conditions.
4. Comparison of two paint systems, A *versus* B on repainting. The two paint systems (each consisting of primer and topcoat) were selected to offer quite different durabilities. From experience, paint system A was known to provide poor protection to steel surfaces. The paints in system B were commercial products purchased from a local paint dealer by a disinterested party. This system was known to provide good protection to iron and steel surfaces.
5. Comparison of a second pretreatment system *versus* an original pretreatment system.

Chemical Pretreatments[2]

Pretreatment X was a mixture of chromic acid, phosphoric acid, a wetting agent, and some zinc dissolved in the phosphoric acid.

Pretreatment Y was a saturated solution of zinc phosphate in an aqueous solution of phosphoric acid.

Pretreatment Z was a homogeneous mixture of phosphoric acid, chromic acid phosphate, water-soluble oil solvent, a wetting agent, and water,

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[1] National Lead Co., Research Laboratories, Brooklyn, N. Y.

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 47, p. 264 (1947).

For details regarding temperature of applications, rinsing, etc., see the earlier report.[2]

TABLE I.—SAYVILLE, LONG ISLAND PANELS.
(Repainted January 11, 1944. 2 coats primer and 1 coat topcoat)

Panel	Surface Condition July, 1939	Corrosion Rating Prior to Repainting January, 1944	Rating Oct. 10, 1944	Rating Sept. 17, 1945	Rating June 19, 1946	Rating June 10, 1947	Rating May 27, 1948
No. 1[a]	Mill scale	1	7	6	6	5	4
No 2	Mill scale	7	10	10	9	8	8
No. 3	Rusted	3	8	7	7	7	6
No. 4	Rusted	4	10	10	9	8	7
No. 5	Sand blast	1	8	6	7	7	6
No. 6	Sand blast	6	10	10	10	10	10
			Pretreatment X				
No. 7L[b]	Mill scale	3	6	4	5	3	3
No. 7R[c]	Mill scale		7	5	5	4	4
No. 8L	Mill scale	7	10	10	10	10	8
No. 8R	Mill scale		10	10	10	9	8
No. 9L	Rusted	2	8	6	7	6	5
No. 9R	Rusted		8	6	7	6	5
No 10L	Rusted	4	10	10	10	7	6
No 10R	Rusted		10	10	9	7	6
No. 11L	Sand blast	1	8	6	7	6	6
No. 11R	Sand blast		8	5	7	6	6
No. 12L	Sand blast	7	10	10	10	10	10
No. 12R	Sand blast		10	10	10	10	10
			Pretreatment Y				
No. 13L	Mill scale	4	9	8	7	6	5
No 13R	Mill scale		9	7	7	6	5
No. 14L	Mill scale	4	10	10	10	8	7
No. 14R	Mill scale		10	10	9	7	7
No. 15L	Rusted	3	8	6	6	5	4
No. 15R	Rusted		8	6	6	5	4
No. 16L	Rusted	6	10	10	10	8	7
No. 16R	Rusted		10	10	10	8	7
No. 17L	Sand blast	4	9	7	7	7	7
No. 17R	Sand blast		9	6	7	7	7
No. 18L	Sand blast	6	10	10	10	9	8
No. 18R	Sand blast		10	10	10	9	8
			Pretreatment Z				
No. 19L	Mill scale	3	9	6	6	5	4
No. 19R	Mill scale		8	5	6	4	4
No. 20L	Mill scale	4	10	10	10	8	6
No. 20R	Mill scale		10	10	9	7	6
No. 21L	Rusted	3	8	6	7	6	4
No 21R	Rusted		8	6	7	6	4
No. 22L	Rusted	2	10	10	10	6	5
No. 22R	Rusted		10	10	10	6	5
No. 23L	Sand blast	3	8	6	7	7	6
No. 23R	Sand blast		7	6	7	7	6
No. 24L	Sand blast	7	10	10	10	9	9
No. 24R	Sand blast		10	10	10	9	9

[a] Odd numbered panels painted with Paint System A—Even numbered panels painted with Paint System B.
[b] L Refers to left half of panel—retreated and repainted.
[c] R Refers to right half of panel—only repainted.

TEST SURFACES AND PAINTS

In the earlier study the panels were 2 by 3 ft. by $\frac{3}{16}$ in. hot-rolled steel representing three surface conditions:

1. Original hot-rolled with mill scale.

2. Hot-rolled with mill scale, allowed to rust and then wire brushed.

3. Hot-rolled with mill scale but thoroughly sand blasted to bare steel before application of paint.

Two exposure locations were selected: Bethlehem, Pa. (an industrial atmosphere), and Sayville, Long Island, N.Y. (a rural atmosphere). Since two paint systems and three chemical pretreatments were involved, and one set of panels without pretreatment, a total of 24 panels was required for exposure at each location. They were exposed at 45 deg. facing south for a period of approximately 53 months (July, 1939 to January, 1944).

TABLE II.—BETHLEHEM, PA. PANELS.
(Repainted February 3, 1944. 1 primer—1 topcoat)

Panel	Surface Condition July, 1939	Corrosion Rating Prior to Repainting February, 1944	Rating Oct. 11, 1944	Rating Sept. 18, 1945	Rating June 20, 1946	Rating June 11, 1947	Rating May 26, 1948
No. 1	Mill scale	2	5	3	3	2	2
No. 2	Mill scale	8	10	9	9	9	9
No. 3	Rusted	3	8	6	6	5	5
No. 4	Rusted	7	10	10	9	9	9
No. 5	Sand blast	6	9	9	9	8	8
No. 6	Sand blast	6	10	10	10	9	9
Pretreatment X							
No. 7L	Mill scale	6	9	7	6	6	5
No. 7R	Mill scale		8	7	6	5	4
No. 8L	Mill scale	8	10	9	8	8	8
No. 8R	Mill scale		10	10	10	10	10
No. 9L	Rusted	4	8	7	6	6	6
No. 9R	Rusted		8	7	6	6	6
No. 10L	Rusted	6	10	9	8	8	8
No. 10R	Rusted		10	9	9	9	9
No. 11L	Sand blast	7	10	9	9	9	9
No. 11R	Sand blast		10	9	9	9	9
No. 12L	Sand blast	9	10	10	10	9	9
No. 12R	Sand blast		10	10	10	10	10
Pretreatment Y							
No. 13L	Mill scale	7	9	8	7	7	7
No. 13R	Mill scale		9	8	7	7	7
No. 14L	Mill scale	10	10	10	10	10	10
No. 14R	Mill scale		10	10	10	10	10
No. 15L	Rusted	2	8	6	6	5	4
No. 15R	Rusted		8	6	6	5	4
No. 16L	Rusted	6	9	8	7	6	6
No. 16R	Rusted		10	9	8	8	7
No. 17L	Sand blast	7	10	9	9	9	8
No. 17R	Sand blast		10	9	9	9	8
No. 18L	Sand blast	10	10	10	10	10	10
No. 18R	Sand blast		10	10	10	10	10
Pretreatment Z							
No. 19L	Mill scale	6	9	7	7	6	5
No. 19R	Mill scale		9	7	7	5	4
No. 20L	Mill scale	8	10	9	8	7	7
No. 20R	Mill scale		10	9	8	8	7
No. 21L	Rusted	2	7	6	6	5	4
No. 21R	Rusted		7	6	6	5	4
No. 22L	Rusted	5	10	9	9	8	8
No. 22R	Rusted		10	9	9	8	8
No. 23L	Sand blast	6	9	9	9	9	7
No. 23R	Sand blast		9	9	9	9	7
No. 24L	Sand blast	10	10	10	10	10	10
No. 24R	Sand blast		10	10	10	10	10

At the end of this exposure cycle the panels varied in corrosion ratings from 1 (totally rusted) to 10 (no rust) when repainted in January, 1944 (see Tables I and II). The left half of each painted and corroded 2 by 3-ft. panel was wire brushed, retreated (chemically), and repainted. The right half was wire brushed and repainted, receiving no second chemical treatment.

PICTORIAL CORROSION STANDARDS

Since this work was started prior to the adoption of any pictorial rusting standards by the A.S.T.M., Subcommittee XXIX used the Swedish pictorial rusting standards for evaluating the degree of corrosion. A comparison of the evaluation made by both reference standards may be noted in the previous report[2] in Table I, columns 8 and 9 and columns 13 and 14.

TABLE III.—DETERMINATION OF OPTIMUM CORROSION PERMISSIBLE BEFORE REPAINTING.

(Surfaces at Sayville)

	Final Value							
	10	9	8	7	6	5	4	3
Corrosion Value just before Repainting	6	7	7	4	3	2	1	3
	7	7	7	4	1	2	3	
	7		7	4	4	4	3	
			6	6	4	4	3	
			6	6	1	2	3	
				4	1	2	3	
				4	4		3	
					4			
					3		3	
					3			

An initial value of 1 had a range from 6 to 4.
An initial value of 2 had a final value of 5 only.
An initial value of 3 had a range from 6 to 3.
An initial value of 4 had a range from 7 to 5.
An initial value of 6 had a range from 10 to 7.
An initial value of 7 had a range from 10 to 8.

Interpretation: To obtain a rating of 10 after 4 years further exposure, the maximum corrosion permissible before repainting at Sayville is approximately 6 on the Swedish scale.

TABLE IV.—DETERMINATION OF OPTIMUM CORROSION PERMISSIBLE BEFORE REPAINTING.

(Surfaces at Bethlehem)

	Final Value								
	10	9	8	7	6	5	4	3	2
Original Value just before Repainting	8	8	6	7	4	3	6		2
	9	7	8	7	4	6	2		
	10	6	6	6	6	6	2		
	10	6	7	8			6		
	10	7	7	8			2		
	10	7	5	6			2		
	10	9	5	6					
	10								

An initial value of 2 had a range from 4 to 2.
An initial value of 3 had a final value of 5 only.
An initial value of 4 had a final value of 6 only.
An initial value of 5 had a final value of 8 only.
An initial value of 6 had a range from 9 to 4.
An initial value of 7 had a range from 9 to 7.
An initial value of 8 had a range from 10 to 9.
An initial value of 9 had a range from 10 to 9.
An initial value of 10 had a final value of 10 only.

Interpretation: To obtain a rating of 10 after 4 years further exposure, the maximum corrosion permissible before repainting at Bethlehem is approximately 8 on the Swedish scale.

TABLE V.—COMPARISON OF PRETREATMENTS X, Y, AND Z AT SAYVILLE BEFORE REPAINTING.

Condition	No Pretreatment	Rank	X	Rank	Y	Rank	Z	Rank
Paint A Mill scale	1	1	3	2.5	4	4	3	2.5
Paint B Mill scale	7	3.5	7	3.5	4	1.5	4	1.5
Paint A Rusted	3	3	2	1	3	3	3	3
Paint B Rusted	4	2.5	4	2.5	6	4	2	1
aint A Sand blasted	1	1.5	1	1.5	4	4	3	3
Paint B Sand blasted	6	1.5	7	3.5	6	1.5	7	3.5
Total		13		14.5		18		14.5

$$X_r^2 = \frac{12}{(np(p+1))}\,[\Sigma(\text{rank totals})^2 - 3n\ (p-1)]$$

where n is the number of replications and p is the number of treatments including the check.

$$X_r^2 = \frac{12}{6\times4\times5}\,[(13^2 + 14.5^2 + 18^2 + 14.5^2) - 18\times5]$$
$$= 0.1 \times 913.5 - 90$$
$$= 91.35 - 90$$
$$= 1.35$$

Interpretation: No difference whether pretreated or not. This is indicated by the totals 13, 14.5, 18, and 14.5. The differences are not great enough to be significant.

TABLE VI.—COMPARISON OF PRETREATMENTS X, Y, AND Z AT BETHLEHEM BEFORE REPAINTING.

Condition	No Pretreatment	Rank	X	Rank	Y	Rank	Z	Rank
Paint A Mill scale	2	1	6	2.5	7	4	6	2.5
Paint B Mill scale	8	2	8	2	10	4	8	2
Paint A Rusted	3	3	4	4	2	1.5	2	1.5
Paint B Rusted	7	4	6	2.5	6	2.5	5	1
Paint A Sand blasted	6	1.5	7	3.5	7	3.5	6	1.5
Paint B Sand blasted	6	1	9	2	10	3.5	10	3.5
Total		12.5		16.5		19		12

$$X_r^2 = 0.1\ (12.^2 + 16.5^2 + 19^2 + 12^2) - 90$$
$$= 93.35 - 90$$
$$= 3.35$$

Interpretation: No difference whether pretreated or not.

STATISTICAL ANALYSIS OF CORROSION DATA

The exposure data accumulated from this series of repretreated and repainted panels exposed to the atmosphere from January, 1944, until May, 1948, can be analyzed statistically. This procedure was therefore used to develop the findings and conclusions which are presented in this report.

TABLE VII.—COMPARISON OF PRETREATMENTS X, Y, AND Z AT SAYVILLE AFTER REPAINTING.

Condition	X	Rank	Y	Rank	Z	Rank
Paint A Mill scale left	3	1	5	3	4	2
Paint A Mill scale right	4	1.5	5	3	4	1.5
Paint A Rusted left	5	3	4	1.5	4	1.5
Paint A Rusted right	5	3	4	1.5	4	1.5
Paint B Sand blasted left	10	3	8	1	9	2
Paint B Sand blasted right	10	3	8	1	9	2
Total		14.5		11		10.5

$$X_r^2 = \frac{12}{6\times3\times4}(14.5^2 + 11^2 + 10.5^2) - 18 \times 4$$
$$= \tfrac{1}{6} \times 441.5 - 72$$
$$= 73.57 - 72$$
$$= 1.58$$

Interpretation: No difference whether pretreated or not.

TABLE VIII.—COMPARISON OF PRETREATMENTS X, Y, AND Z AT BETHLEHEM AFTER REPAINTING.

Condition	X	Rank	Y	Rank	Z	Rank
Paint A Mill scale left	5	1.5	7	3	5	1.5
Paint A Mill scale right	4	1.5	7	3	4	1.5
Paint B Rusted left	8	2.5	6	1	8	2.5
Paint B Rusted right	9	3	7	1	8	2
Paint A Sand blasted left	9	3	8	2	7	1
Paint A Sand blasted right	9	3	8	2	7	1
Paint B Sand blasted left	9	1	10	2.5	10	2.5
Paint B Sand blasted right	10	2	10	2	10	2
Total		17.5		16.5		14

$$X_r^2 = \frac{12}{8\times3\times4}(17.5^2 + 16.5^2 + 14^2) - 24 \times 4$$
$$= \tfrac{1}{8}(774.5) - 96$$
$$= 96.8125 - 96$$
$$= 0.8125$$

Interpretation: No difference whether pretreated or not.

The type of analysis used to determine the difference between two sets of data is called a "Rank Method"[3] which is very useful when no assumptions as to the normalities of data can be made. In addition, it is useful when the measurements made are made in some system of ranking such as the Swedish pictorial system with which this report is concerned.

TABLE IX.—COMPARISON OF CONDITIONING METHODS AT SAYVILLE AFTER REPAINTING.

Condition	Mill Scale	Rank	Rusted	Rank	Rusted Sand Blasted	Rank
Paint A pretreatment X left	3	1	5	2	6	3
Paint A pretreatment X right	4	1	5	2	6	3
Paint A pretreatment Y left	5	2	4	1	7	3
Paint A pretreatment Y right	5	2	4	1	7	3
Paint A pretreatment Z left	4	1.5	4	1.5	6	3
Paint A pretreatment Z right	4	1.5	4	1.5	6	3
Total		9		9		18

$$X_r^2 = \frac{12}{6\times3\times4}(9^2 + 9^2 + 18^2) - 18 \times 4$$
$$= \tfrac{1}{6}(486) - 72$$
$$= 81 - 72$$
$$= 9$$

Interpretation: Sand blasted surfaces rusted give better paint life than either of the other 2 surfaces. This can be seen from the differences in the rank totals of rusted mill scale and sandblasted rusted panels .

TABLE X.—COMPARISON OF CONDITIONING METHODS AT BETHLEHEM AFTER REPAINTING.

Condition	Mill Scale	Rusted Sand Blasted	Difference	Rank (all plus)
Paint B	9	9	0	
Paint A pretreatment X left	5	9	4	6
Paint A pretreatment X right	4	9	5	7
Paint B pretreatment X left	8	9	1	2
Paint B pretreatment X right	10	10	0	
Paint A pretreatment Y left	7	8	1	2
Paint A pretreatment Y right	7	8	1	2
Paint B pretreatment Y left	10	10	0	
Paint B pretreatment Y right	10	10	0	
Paint A pretreatment Z left	5	7	2	4.5
Paint A pretreatment Z right	4	7	2	4.5
Total				28

Interpretation: Rusted, sand blasted surfaces give better paint life than rusted, mill scale surfaces, since in no case is there any minus difference and in the other cases the difference is zero or plus.

Briefly, the method is as follows: The data are grouped in pairs in which the only difference between the two items in the pair is the factor under consideration and all other factors are identical. Then the difference between the two items in each pair are tabulated and the differences are given a rank with the lowest difference ranked 1, etc. The ranks of the minus differences are then given minus signs and added and the ranks of the plus differences given plus signs and added. The lowest sum is then entered in a table supplied by Wilcoxon[4] and it is noted directly whether the series are significantly different.

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[3] Milton Friedman, "The Use of Rank to Avoid the Assumption of Normality," *Journal*, American Statistical Association, Vol. 32, pp. 675–701 (1937).

TABLE XI.—COMPARISON OF PAINT SYSTEMS A AND B AT SAYVILLE AFTER REPAINTING.

Condition	A	B	Difference	Rank
Mill scale	4	8	4	
Rusted	6	7	1	
Sand blast	6	10	4	
Mill scale pretreatment X left	7	8	5	
Mill scale pretreatment X right	4	8	4	All
Rusted pretreatment X left	5	6	1	Plus
Rusted pretreatment X right	5	6	1	
Sand blast pretreatment X left	6	10	4	
Sand blast pretreatment X right	6	10	4	
Mill scale pretreatment Y left	5	7	2	
Mill scale pretreatment Y right	5	7	2	
Rusted pretreatment Y left	4	7	3	
Rusted pretreatment Y right	4	7	3	
Sand blast pretreatment Y left	7	8	1	
Sand blast pretreatment Y right	7	8	1	
Mill scale pretreatment Z left	4	6	2	
Mill scale pretreatment Z right	4	6	2	All
Rusted pretreatment Z left	4	5	1	Plus
Rusted pretreatment Z right	4	5	1	
Sand blast pretreatment Z left	6	9	3	
Sand blast pretreatment Z right	6	9	3	

Interpretation: Paint System B gives better performance than Paint System A, since the differences are all plus.

TABLE XII.—COMPARISON OF PAINT SYSTEMS A AND B AT BETHLEHEM AFTER REPAINTING.

Condition	A	B	Difference	Rank
Mill scale	2	9	7	
Rusted	5	9	4	
Sand blasted	8	9	1	
Mill scale pretreatment X left	5	8	3	
X right	4	10	6	
Rusted pretreatment X left	6	8	2	
X right	6	9	3	All
Sand blasted pretreatment X left	9	9	0	Plus
X right	9	10	1	
Mill scale pretreatment Y left	7	10	3	
Y right	7	10	3	
Rusted pretreatment Y left	4	6	2	
Y right	4	7	3	
Sand blasted pretreatment Y left	8	10	2	
Y right	8	10	2	
Mill scale pretreatment Z left	5	7	2	
Z right	4	7	3	
Rusted pretreatment Z left	4	8	4	
Z right	4	8	4	
Sand blasted pretreatment Z left	7	10	3	
Z right	7	10	3	

Interpretation: Paint System B gives better performance than Paint System A, since the differences are all plus.

TABLE XIII.—COMPARISON OF ONE PRETREATMENT SYSTEM TO TWO PRETREATMENT SYSTEM AT SAYVILLE.

Condition	One	Two	Difference	Rank
Mill scale paint A pretreatment X	4	3	−1	−1
Mill scale paint B pretreatment X	8	8	0	
Rusted paint A pretreatment X	5	5	0	
Rusted paint B pretreatment X	6	6	0	
Sand blasted paint A pretreatment X	6	6	0	
Sand blasted paint B pretreatment X	10	10	0	
Mill scale paint A pretreatment Y	5	5	0	
Mill scale paint B pretreatment Y	7	7	0	
Rusted paint A pretreatment Y	4	4	0	
Rusted paint B pretreatment Y	7	7	0	
Sand blasted paint A pretreatment Y	7	7	0	
Sand blasted paint B pretreatment Y	8	8	0	
Mill scale paint A pretreatment Z	4	4	0	
Mill scale paint B pretreatment Z	6	6	0	
Rusted paint A pretreatment Z	4	4	0	
Rusted paint B pretreatment Z	5	5	0	
Sand blasted paint A pretreatment Z	6	6	0	
Sand blasted paint B pretreatment Z	9	9	0	
Total				−1

Interpretation: No advantage in using chemical pretreatments on a partially painted-partially corroded surface which was originally pretreated, painted, and exposed in a rural atmosphere.

TABLE XIV.—COMPARISON OF ONE PRETREATMENT SYSTEM TO TWO PRETREATMENT SYSTEM AT BETHLEHEM, PA.

Condition	One	Two	Difference		Rank
Mill scale paint A pretreatment X	4	5	1	3	
Mill scale paint B pretreatment X	10	8	−2		−6
Rusted paint A pretreatment X	6	6	0		
Rusted paint B pretreatment X	9	8	−1		−3
Sand blasted paint A pretreatment X	9	9	0		
Sand blasted paint B pretreatment X	10	9	−1		−3
Mill scale paint A pretreatment Y	7	7	0		
Mill scale paint B pretreatment Y	10	10	0		
Rusted paint A pretreatment Y	4	4	0		
Rusted paint B pretreatment Y	7	6	−1		−3
Sand blasted paint A pretreatment Y	8	8	0		
Sand blastedpaint B pretreatment Y	10	10	0		
Mill scale paint A pretreatment Z	4	5	1	3	
Mill scale paint B pretreatment Z	7	7	0		
Rusted paint A pretreatment Z	4	4	0		
Rusted paint B pretreatment Z	8	8	0		
Sand blasted paint A pretreatment Z	7	7	0		
Sand blasted paint B pretreatment Z	10	10	0		
Total				6	−15

Interpretation: No advantage in using chemical pretreatments on a partially painted-partially corroded surface which was originally pretreated, painted, and exposed in an industrial atmosphere.

Where more than two series are to be

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[4] Frank Wilcoxon, "Individual Comparison by Ranking Methods," *Biometrics Bulletin 1*, pp. 80–82 (1945).

compared, as in the case of the three different pretreatments and the no pretreatment check, the system is slightly different. It is described by Bliss.[5]

Tables III and IV show the maximum degree of corrosion permissible before repainting at both Sayville and Bethlehem became necessary in order to maintain economical protection. These tables might also be considered to show the relationship between the degree of rusting at the time of repainting and the protection after repainting. They are set up using the final value obtained as a rating on May 27, 1948 (Table I) as column headings and in each column the corresponding value of the panel when it was repainted in January 1944. For example, panel No. 1 had a value of 1 when it was repainted in January, 1944, and in May, 1948, it had a value of 4. Under the 4 column, a 1 would be placed. Then when all the panels are recorded in this manner, a tabulation is made showing the maximum final value to be expected from the value at repainting. Again, as an example, an initial value of 1 can go as high as 6 since a 1 appears in the column headed 6.

To make use of these statistical tables, the maintenance engineer must use his judgment. He, must select some final rusting rating as the goal, then the lowest initial rusting rating that can give the selected final rating is the maximum corrosion allowable before repainting.

CONCLUSIONS

From a statistical analysis of the data the following conclusions are valid:

1. For the type of weathering at Sayville, Long Island, N. Y. (rural environment) the maximum corrosion permissible before repainting for the best and most economical protection is 6 on the Swedish pictorial rusting standards. For Bethlehem Pa. (industrial environment) the maximum corrosion permissible is 8. Thus earlier repainting is indicated in an industrial atmospheric environment. A Swedish rating of 6 and 8 is approximately equal to an A.S.T.M. rating of 7 and 8, respectively.

NOTE.—The time for most economical repainting based on the *practical experience* and *judgment* of Subcommittee XXIX is at corrosion rating of 8, and that it is definitely necessary at a corrosion rating of 6.

2. There is no difference in the performance of any of the three pretreatment systems (Tables V to VIII) as compared with no pretreatment at the time of repainting or at either exposure station.

3. At both stations, for repainting purposes, painted sand blasted panels, allowed to partially rust were less difficult to protect than painted mill scale panels allowed to partially rust.

4. After repainting, paint system B give significantly better protection than paint system A. This was true at both stations (Tables IX to XII). This is the same order of performance as was found for the initial paint tests.

5. There is no significant difference in corrosion protection between panels with one pretreatment (Tables XIII and XIV) or two pretreatments (the second pretreatment given at the time of repainting). This was true in both a rural and an industrial environment.

Acknowledgment:

Subcommittee XXIX gratefully acknowledges the assistance of William E. Moyer[1] for the statistical analysis of the data in this report.

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[5] C. I. Bliss, "A Chart of the Chi-Square Distribution," *Journal*, American Statistical Association, Vol. 39, pp. 246-248 (1944).

REPORT OF COMMITTEE D-2
ON
PETROLEUM PRODUCTS AND LUBRICANTS*

Committee D-2 on Petroleum Products and Lubricants and a number of its subcommittees held two meetings during the past year: one in February, 1949, at Washington, D. C., and one in June, 1949, at Atlantic City, N. J. In addition, a large number of subcommittees held meetings in November, 1948, at Chicago, Ill.

The voting membership of the committee is now 100, of whom 43 are classified as producers, 38 as consumers, and 19 as general interest members. These figures bear witness to the fact that Committee D-2 is filling its proper rôle as a cooperative, neutral meeting ground for the producers and consumers of petroleum products.

The total voting membership has increased very little during the past year. However, the number of individuals participating in the work of the committee has increased from more than 600 to approximately 700. This increase indicates that the work of the committee is growing in response to the demands of industry.

CHANGES IN COMMITTEE ORGANIZATION

Every effort is being made to complete a major rearrangement of the subcommittee structure of Committee D-2 within the next year. This rearrangement, which was initiated more than two years ago, calls for a new working philosophy on the part of Committee D-2 members, based on the concept of two coexisting types of subcommittees: Technical Committees, which have the responsibility for studying the performance of products in service, and Research Divisions, which deal primarily with the development and maintenance of standard methods. These two types of groups will complement each other in working toward the development of significant methods of test. Most of the proposed Research Divisions are consolidations of former subcommittees; and, therefore, no change in these activities of Committee D-2 is involved.

Coordinating Divisions will also be included to perform the necessary controlling and auxiliary functions. In addition to those already functioning under other names, the Advisory Committee has authorized the formation of a new Coordinating Division on Research under the chairmanship of H. P. Ferguson. It will be the assignment of this Division to prepare an outline of the unsolved research problems embodied in the scope and activities of Committee D-2.

The details of this rearrangement have not yet been completed but will be reported to the Society at a later date.

RECOMMENDATIONS ACCEPTED BY ADMINISTRATIVE COMMITTEE ON STANDARDS

The large number of actions taken at the June, 1948, meeting of Committee D-2 made necessary the preparation of a Supplementary Report which was submitted to letter ballot of the committee in August, 1948. The recommendations in this Supplementary Report were referred to the Administrative Committee on Standards and were accepted by it on September 29, 1948. The Supplementary Report and the actions of the Administrative Committee on Standards are included in the 1948 *Proceedings*[1] and also in the 1948 compilation of A.S.T.M. Standards on Petroleum Products and Lubricants.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

American Standards

On the basis of actions of the Society during 1948, the following recommendations have been submitted through Sectional Committee Z11 on Petroleum Products and Lubricants to the American Standards Association:

Approve as American Standards:
Tentative Methods of Test for:

Cone Penetration of Lubricating Grease D 217-47 T; ASA No. Z11.3-1948
Sulfated Residue, Lead, Iron and Copper in New and Used Lubricating Oils D 810-47 T; ASA No. Z11.57-1948
Chemical Analysis for Metals in Lubricating Oils D 811-44 T; ASA No. Z11.56-1948
Sediment in Fuel Oil by Extraction D 473-46 T; ASA No. Z11.58-1948

Reapprove as Revised American Standards:

Standard Definitions of Terms Relating to Petroleum D 288-47; ASA No. Z11.28-1948
Standard Method of Test for Knock Characteristics of Motor Fuels by the Motor Method D 357-47; ASA No. Z11.37-1947

Withdrawal of American Standards:

Standard Method of Test for Tetraethyl Lead in Gasoline D 526-42; ASA No. Z11.42-1942

The above recommendations are still under consideration by the American Standards Association in addition to the additional recommendations to be submitted to the American Standards Association concerning the withdrawal as American Standards of the Standard Methods of Sampling Petroleum and Petroleum Products (D 270-33); (ASA Z11.33-1935) and the Standard Method of Test for Saponification Number of Petroleum Products by Color-Indicator Titration (D 94-45); (ASA Z11.20-1945).

Activities of Technical Committees and Subcommittees

Technical Committee A on Gasoline (H. M. Smith, chairman) has been active in several fields of endeavor, as follows:

Section I on Gum (C. A. Neusbaum, chairman) reviewed the methods for determination of gum content and oxygen stability of gasoline and has recommended changes in the status of three of these methods.

Methods D 381-46, Test for Existent Gum in Gasoline, and D 525-46, Oxygen Stability of Gasoline, require minor changes involving the dimensions of the apparatus. In one case, the change is dictated by a corresponding change in the glassware available from the glass manufacturers. In the other case, dimensions have been changed for purposes of clarity. These revisions do not affect the results obtained by the method.

Section I also proposed that Method D 873-46 T, Test for Oxygen Stability of Aviation Gasoline, be adopted as standard, with the addition of a paragraph relative to the measurement of the visible lead precipitate and with editorial changes which have been made in order to reconcile Method D 873 with the Air Force-Navy Aeronautical Specification AN-F-58 for Fuel, Aircraft Turbine and Jet Engine.

Section I is currently investigating the feasibility of standardizing a method for the determination of existent gum and oxygen stability in Diesel fuels and light fuel oils. The method under investigation is similar to Method D 381, with the exception that evaporation takes place at 600 F., instead of 310 F., in an atmosphere of superheated steam.

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 48, p. 287 (1948).

Section V on Specifications and Significance of Tests (H. C. Dickinson, chairman) is carrying on a special investigation of climatic conditions throughout the country as they affect the vapor pressure of gasoline. In addition, it is proposing that Specifications D 439 be brought up to date by changing the year in footnote *d* of the specifications relative to sulfur content from "1940" to "1949."

Section VII on Tetraethyllead (C. M. Gambrill, chairman) is planning to hold a symposium in February, 1950, which has tentatively been titled "Recent Developments in Instrumental Methods for the Determination of Tetraethyllead in Gasoline."

Section VIII on Sludge and Varnish Characteristics of Motor Fuels (S. S. Kurtz, Jr., chairman) is currently investigating three proposed methods for the measurement of the sludge-forming tendency of fuels. This work is proceeding slowly and is being coordinated with a similar program being carried on in the Coordinating Research Council.

Technical Committee B on Lubricating Oils (W. S. James, chairman) sponsored an informal symposium on the subject of Valve Burning, to be held in June, 1949, at Atlantic City. It is also planning a Symposium on High-Additive Content Oils for the Pacific Area National Meeting of the Society in San Francisco, Calif., in October, 1949. The subject of motor oil classifications is currently commanding considerable attention in technical Committee B. The Special Subcommittee on Crankcase Oils Classification, headed by J. L. McCloud, is making considerable progress in crystallizing the thoughts of producers and consumers on this subject.

Section U-III on Industrial Gear Oils (C. L. Pope, chairman) is studying the various properties of gear oils that may affect field performance. Particular attention is being given to viscosity classification and foaming. The Section is planning to request the Research Division on Flow Properties to study and develop a channel test. An informal Symposium on Industrial Gear Lubricants was sponsored by this Section at the 1948 meeting in Detroit at which the following papers[2] were given:

"Heavy Duty Gear Oils," by E. M. Kipp, I. S. Kolarik, and C. A. Zeiler, Aluminum Co. of America.

"Gear Lubricants Used in Steel Plants," by John F. Pelly, Bethlehem Steel Co.

"Gear Set Servicing by the Cathode Ray Oscilloscope," by A. R. Purdy and J. H. Goffe, Socony Vacuum Oil Co.

Section U-V on Instrument Oils (E. H. Erck, chairman) is studying the behavior of instrument oils in service and the properties which affect performance. A test method is being developed for measuring oxidation stability.

Section U-VI on Lubricants for Air Compressors and Compressed Air Tools (C. M. Larson, chairman) is directing its principal activity to date in the direction of establishing a significant classification of lubricants for air compressors based on type, horsepower, speed, pressures, etc. Future work will seek information on lubrication practices and service problems.

Section Q-III on Foaming (H. A. Ambrose, chairman) has succeeded in finding a satisfactory source of supply for the diffuser stone used in Method D 892 – 46 T for Foaming Characteristics of Crankcase Oils.

Section Q-IV on Viscosity Stability (W. Van Horne, chairman) has a definite work program under way, determining the effect of various types of working devices on viscosity stability, using the same four oils being tested for viscosity at various rates of shear under a project sponsored by the American Petroleum Institute.

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[2] Issued as a separate publication, *STP No. 88*, April, 1949.

Section U-II on Automotive Gear Oils (H. C. Mougey, chairman) and Section U-IV on Hydraulic Power Transmission Liquids (H. R. Wolf, chairman) are inactive at the moment but have been organized to develop and standardize test methods as soon as the respective projects in the Coordinating Lubricants Research Committee and other technical groups have reached the desired stage of development.

Technical Committee B has been authorized to form a new section which will study and develop a method or methods for measuring the dilutions of crankcase oils from both gasoline and Diesel engines. The present Method D 322 - 35, Test for Dilution of Crankcase Oils, cannot be employed for used oils from Diesel engines and is not completely satisfactory for those from gasoline engines.

Technical Committee C on Turbine Oils (F. C. Linn, chairman) sponsored a Symposium on Lubrication of High-Speed Turbine Gear Equipment on February 14, 1949, comprising the following four papers:[3]

"Lubrication of Naval Gearing," by Commodore R. T. Simpson, U. S. Navy,

"Developments in Gear Design and Their Lubrication Requirements," by L. J. Collins, General Electric Co.,

"Physical Concepts of the Establishment of the Lubricating Oil Wedge and Its Associated Load-Carrying Capacity for the Mating Tooth Surfaces of High-Speed Gears," by E. K. Gatcombe, United States Naval Academy, and

"Fundamentals of Worm Gear Lubrication," by A. R. Purdy, Socony Vacuum Oil Co.

Technical Committee C is also planning a Symposium on the Lubrication of Turbine Equipment to be held at the Pacific Area National Meeting of the Society in San Francisco in October, 1949.

Committee D-2 approved the extension of the scope of Technical Committee C to cover the lubrication of non-aircraft gas turbines.

Section I on Oil Systems of Turbines (F. E. Rosenstiehl, chairman) is currently working on the draft of a recommended practice for the cleaning of turbine lubricating systems in preparation for service testing.

Section II on Rusting (W. P. Kuebler, chairman) is currently carrying on cooperative work to improve Method D 665 - 47 T, Test for Rust-Preventing Characteristics of Steam Turbine Oils in the Presence of Water, prior to recommending its adoption as standard. It is proposing, at this time, that the length of test be shortened from "48" to "24" hr. It has been the experience of the section that in the case of an oil that will allow rusting, the rust will form within the first few hours. This naturally would be evidence sufficient to reject the oil. However, in evaluating the degree of rust formation it is felt that the test should run at least 24 hr.

Section III on Oxidation of Turbine Oils (E. A. Reehl, chairman) is carrying on cooperative work to determine the proper means of judging turbine oil quality. The results of this work will give indications as to the relative significance of increasing neutralization value and increasing sludge content, in so far as service performance is concerned, and will show whether sludge precedes, parallels, or follows rising neutralization value.

Section IV on Emulsion Tests (M. D. Baker, chairman) is endeavoring to develop a constructive program that will produce an emulsion test which can be used for specification purposes and one that will predict the behavior of an oil in service.

Section V on Oil Film Strength Testing (C. D. Wilson, chairman) is preparing definitions for oiliness, load-carrying capacity, and film strength. It is also continuing its studies of testing equipment which will show the film strength characteristics as indicated by the point of film break-down.

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[3] Issued as a separate publication, *STP No. 92*, August, 1949.

Technical Committee E on Burner Fuel Oils (M. A. Powers, chairman) is keeping in touch with developments in the burner fuel field but, at present, has no active projects under way.

Technical Committee F on Diesel Fuels (C. G. A. Rosen, chairman) is giving careful study to the development of problems which should come within its scope. An open discussion on this subject took place at the February meeting of this committee, and it was agreed to arrange a Symposium on The Effect of Fuel on Diesel Engine Deposits for the fall meeting in San Francisco.

Approval was also given for the establishment of a section to work in connection with Subcommittee XXV on Analysis of Petroleum Products for Hydrocarbon Types (Research Division IV on Hydrocarbon Analysis) on the further study of hydrocarbons in the Diesel oil range, directing the work toward improving combustion characteristics.

Section II on Specifications (H. M. Gadebusch, chairman) is preparing revisions of Specifications D 975 – 48 T, for Diesel Fuel Oil.

Technical Committee G on Lubricating Greases (R. C. Adams, chairman) has been reorganized during the past year to provide approximately 13 subsections, each working on the development, evaluation, or standardization of a specific test method.

Two new subsections are being organized, the first to cooperate with Subcommittee XI on the development of methods for the determination of extreme-pressure elements in lubricants, and the second to develop a method for the chemical corrosiveness of greases.

Technical Committee G has presented, at this time, the following two proposed methods appearing in Appendices I and II for publication as information: Proposed Method of Test for Micro-Cone Penetration of Lubricating Greases, and Proposed Method of Test for the Apparent Viscosity of Lubricating Greases. The first method fills a need for determining consistency when the small size of the sample precludes the use of Method D 217 – 48, Test for Cone Penetration of Lubricating Grease; the second provides a means for measuring the flow properties of greases in usable engineering units. Both of these methods are the outgrowth of the work being carried on by Section II on Consistency Measurements and Related Physical Tests for Lubricating Greases (E. W. Adams, chairman).

Technical Committee H on Light Hydrocarbons (W. G. Lovell, chairman) has been extremely active during the past year and is presenting proposals, at this time, relating to eight methods of test, as follows:

Section II on Natural Gasoline (R. C. Alden, chairman) has presented an editorially improved version of Method D 323 – 43, Test for Vapor Pressure of Petroleum Products (Reid Method) as appended hereto.[4] This revision involves considerable rearrangement of the material in behalf of lucidity and consecutiveness, elimination of provisions relating to sampling which will be incorporated in the forthcoming A.S.T.M. Manual on Measuring and Sampling of Petroleum and its Products, now in preparation by Subcommittee XV, and the addition of a set of precautions which emphasize certain steps where carelessness most often results in errors. It is hoped that the resulting method will lead to greater accuracy and ease of operation. Section II is currently engaged in preparing tables of physical constants of light hydrocarbons and in comparing notes on null point instruments for vapor pressure measurement.

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[4] This revised method was accepted by the Society and appears in the 1949 Book of A.S.T.M. Standards, Part 5.

Section III on Chemical Utilization, Including Pure Hydrocarbons (R. F. Dunbrook, chairman) is proposing that three methods of test for Separation of Residue from Butadiene, Determination of Butadiene Dimer in Polymerization Grade Butadiene, and Determination of Nonvolatile Residue of Polymerization Grade Butadiene, which were published in the 1948 Report of Committee D-2 as Appendices II, III, and IV,[1] respectively, be accepted as tentatives at this time. Since their publication as information, these methods have continued in use in all commercial operations without suggestion for major modifications.

Section III is proposing that the following three methods be accepted for publication as tentative: Test for Oxygen in Butadiene Vapors by the Manganous Hydroxide Method, Test for Acetylene in Polymerization Grade Butadiene by Silver Nitrate Method, and Test for Peroxides in Butadiene by Ferrous Titanous Method, as appended hereto.[5] This is the first publication of these methods by A.S.T.M.; however, they have all been in use commercially throughout the petroleum industry since before the end of the war without major modifications.

Section III is also proposing for publication as information a Proposed Method of Test for Determination of Boiling Point Range of Polymerization-Grade Butadiene as it appears in Appendix VIII. This method has had a history similar to that of the methods listed above. However, approval for the official thermometer described in Appendix B to this method has not yet been received.

Section III plans to take up as its next project improvements in the Rubber Reserve Butadiene methods which have heretofore been accepted with editorial revision only.

Section VI on Liquefied Petroleum Gas (G. R. Benz, chairman) has referred the several testing methods pertaining to liquefied petroleum gas back to their sponsoring bodies for improvement and verification. It has also initiated considerable work on methods for the determination of vapor pressure, specific gravity, sulfur, and corrosion. Three temporary working groups have been appointed by Technical Committee H to coordinate work on these subjects.

Technical Committee J on Aviation Fuels, under its new chairman, J. T. Hendren, has undergone a reevaluation of its organization and objectives. Active work is being carried on by all the sections, involving studies in their respective fields.

Technical Committee K on Cutting Fluids (O. L. Maag, chairman).—Sections I on Laboratory Evaluation of Cutting Fluids (T. G. Roehner, chairman) and II on Plant Evaluation of Cutting Fluids (M. E. McKinney, chairman) are actively engaged in developing methods for the evaluation of the behavior of cutting fluids. However, work has not progressed on these problems to the point where formal methods can be written.

Section III on Nomenclature, Definition, and Classification of Cutting Fluids (O. W. Boston, chairman) finished the Proposed Definitions, Functions, Types and Designations of Cutting Fluids which are presented as information in Appendix III.

Technical Committee L on Tractor Fuels (E. M. Hughes, chairman) has reevaluated its objectives during the past year and is currently engaged in surveys among the producers and consumers of tractor fuels which should indicate the direction along which further work will be undertaken.

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[1] These methods were accepted as tentative by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 5.

Research Division I on Combustion Characteristics (D. B. Brooks, chairman) has continued to be active in the development and improvement of the knock testing methods.

Section IV on Test Equipment (B. R. Siegel, chairman) has submitted a write-up describing the rating of high vapor-pressure fuels with the Waukesha carburetor jacket GP 214-269. The purpose of this special carburetor jacket is to permit the rating of fuels which would be subject to vapor lock under normal operating conditions. It has been tested extensively by the members of Section IV and found to be of satisfactory design. At the request of the Division, this description appears in Appendix IV. It may be recommended for inclusion in the A.S.T.M. Manual of Engine Test Methods for Rating Fuels at a later date.

Upon the suggestion of Section V on Reference Materials (F. C. Burk, chairman), Research Division I is proposing a change in the specification tolerances for the density and refractive index of ASTM *iso*octane and *n*-heptane, which will require appropriate revisions in Methods D 357 - 48, D 614 - 48 T, D 908 - 48 T, and D 909 - 48 T.

Research Division I is currently sponsoring three major projects, as follows:

1. A study of the reproducibility of the CRC F-21 procedure for rating aviation fuels.

2. A study of the effect of barometric pressure changes on the rating of fuels.

3. A continuation of the National Exchange Group cooperative program for maintaining accurate operation of knock test engines.

Research Division X on Corrosion Tests (F. D. Tuemmler, chairman) has completed its first year's work by preparing a tentative revision of Method D 130 – 30, Test for Detection of Free Sulfur and Corrosive Sulfur Compounds in Gasoline, as appended hereto.[5] This revised method incorporates the following:

1. All current procedures appearing in D-2 specifications.

2. A common improved method for preparation of the copper strip.

3. Control of several operational limits currently subject to varying interpretations.

The revised method will not attempt to define what interpretations are to be given to the differently colored strips obtained other than to repeat the criteria given in established A.S.T.M. specifications under the jurisdiction of Committee D-2. The future program is to be directed toward the establishment of a graded series of strips based on two slightly different proposals. Further consideration also will be given to some uniform simplification of the procedures appearing in the presently recommended revision of Method D 130.

Subcommittee I on Pharmaceutical Tests (C. F. W. Gebelein, chairman) has completed a recent cooperative program on Method D 937 - 47 T, Test for Penetration of Petrolatum. In this program, the following items were investigated:

1. The use of a rigid aluminum container to prevent surface working of the petrolatum.

2. Establishment of closer limits on air and water bath conditioning times and temperatures.

3. The establishment of reproducibility and repeatability limits.

The changes included in this program have been incorporated in a fourth revision of Method D 937, as appended hereto.[4]

Subcommittee I is also recommending the adoption as standard of Method D 938 - 47 T, Test for Congealing Point of Pharmaceutical Petrolatums, because of satisfactory acceptance of this method by both consumers and producers of petrolatum.

Subcommittee III on Paraffin Wax (J. B. Rather, Jr., chairman) completed revisions of two methods under its jurisdiction, as follows:

It has proposed revisions in Method D 127 - 40, Test for Melting Point of Petrolatum, which will permit the use of this method with high-melting-point microcrystalline wax. This is in accord with accepted practice. The necessary revisions include changes in title and scope and the specification of a new thermometer.

This subcommittee has proposed the publication of a semi-micro Method of Test for Oil Content of Paraffin Wax, as a tentative revision of Method D 721 - 47, Test for Oil Content of Paraffin Wax. The semi-micro method, as appended hereto,[5] is identical with the current method in procedure and magnitude of results. It differs only in sample size and complexity of apparatus, and present indications are that it is more accurate than the current method.

Subcommittee V on Viscosity (J. C. Geniesse, chairman) is working on a revision of Method D 445 - 46 T, Test for Kinematic Viscosity. The essential changes incorporated in this revision will be the deletion of the sections on calibration as outlined in Methods A and B in the Appendix, and the detailing of the calibration procedure in Section 4.

Subcommittee VI on Color (H. M. Hancock, chairman) has prepared a simplified version of the Proposed Method of Test for Color Index of Petroleum Products by Photoelectric Colorimeter which was published in the 1947 Report of Committee D-2.[6] This simplified method is republished as information in Appendix V.

Subcommittee VI is recommending for immediate adoption two minor changes in Method D 156 - 38, Test for Color of Refined Petroleum Oils by Means of Saybolt Chromometer. These additions are made for the purpose of formalizing a sample drying procedure now used in a number of laboratories. In addition, it is currently conducting cooperative work for the purpose of developing repeatability and reproducibility values to be incorporated into this method. Subcommittee VI is also attempting to improve the standardization of the color standards in Method D 155 - 45 T, Test for Color of Lubricating Oil and Petrolatum by Means of A.S.T.M. Union Colorimeter.

Subcommittee VII on Sulfur Determination (H. M. Hancock, chairman), in conjunction with Section A of Subcommittee XI, is proposing, at this time, the resolution of the overlapping Methods D 129 - 44, Test for Sulfur in Petroleum Oils by the Bomb Method, and D 894 - 48 T, Test for Sulfur in Lubricating Oils Containing Additives and in Additive Concentrates by Bomb Method. A combination of the two methods is felt justified as the result of a lengthy study of this problem and certain revisions which have been made in Method D 894. Method D 129, revised as appended hereto,[4] includes the text of Method D 894, with appropriate editorial changes.

Subcommittee VII is also recommending the republication of the Proposed Method of Test for Sulfur in Petroleum Products by the $CO_2 - O_2$ Lamp Method, which was first published, as information only, in the 1947 Report of Committee D-2.[6] The reasons for this request are that this method is being used currently by a large and increasing number of laboratories, and that the subcommittee wishes to add to it a supplement giving cooperative data which indicate the definite advantages of this method over Method D 90 - 47 T, Test for Sulfur in Petroleum Products by the Lamp-Gravimetric Method. This proposed method and the new supplement appear in Appendix VI.

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[6] *Proceedings*, Am. Soc. Testing Mats., Vol. 47, p. 271 (1947).

Subcommittee VIII on Distillation (E. W. Dean, chairman).—Section A on Vacuum Distillation under its new chairman, J. F. Middleton, is continuing its investigation of the variables involved in the development of a standard vacuum distillation procedure. This program is proceeding slowly but successfully.

Subcommittee XI on Determination of Inorganic Elements in Lubricants (C. M. Gambrill, chairman) recommends:

1. That the Proposed Method of Test for Sodium in Lubricating Oils and Lubricating Oil Additives, which was published as information with the 1948 Report of Committee D-2,[1] be published as tentative, with certain minor changes, and

2. That a Method for the Determination of Phosphorus be published as information which consists of a combination of the Proposed Method of Test for Phosphorus in Organic Material published with the 1946 Report of Committee D-2,[7] for phosphorus contents of 0.5 per cent and above, and the test currently in use for phosphorus contents below 2 per cent. This combined method appears in Appendix IX.

Subcommittee XI is also working on a revision of Method D 808 - 44 T, for Chlorine in Lubricating Oils by the Bomb Method and is planning a cooperative program with Technical Committee G for the determination of sulfur, chlorine, phosphorus, and lead in lubricating greases.

Subcommittee XIII on Neutralization Number and Saponification (H. P. Ferguson, chairman) recommended the adoption as standard of Method D 664 - 46 T, Test for Neutralization Value (Acid and Base Numbers) by Electrometric Titration. The subcommittee finds that this method which has been published as tentative for seven years, represents current practices and has been accepted widely in the industry for the purpose for which it was intended.

Subcommittee XV (Division II) on Measurement and Sampling (L. C. Burroughs, chairman) is in the process of preparing a comprehensive A.S.T.M. Manual on Measuring and Sampling Petroleum and its Products. The first section of this manual will contain methods for sampling, gaging, and measuring the temperature of petroleum and petroleum products. This material, together with certain auxiliary information, is now complete but was not available in time for inclusion in this report. Its preparation will be expedited, and, since the necessary recommendations will involve tentatives only, it will be referred to the Administrative Committee on Standards as soon as possible. Subcommittee XV is proposing at this time that general approval be given to the publication of the methods prepared under its sponsorship in a bound volume, separate from the compilation of A.S.T.M. Standards on Petroleum Products and Lubricants.

Sections D, on Units of Measurement, Calculations, and Tables (B. J. Heinrich, chairman), and E, on Tank Calibration (H. C. Packard, chairman), are making considerable progress in the preparation of the drafts of the remainder of this manual.

Subcommittee XVI on Cloud and Pour Test (J. J. Giammaria, chairman) is continuing its long-range studies for the purpose of correlating the laboratory tests for pour point and pour point stability with field performance. Sufficient information has now been obtained for certain of the pour stability tests to be written up in A.S.T.M. form for publication as information. These drafts should be available within the next year.

Subcommittee XVI is also working on modifications of the present pour test equipment, an editorial revision of the present Cloud and Pour Test Method, D 97 - 47, an investigation of mercury-thallium thermometers for use in the range −70 F. to 70 F., and the reproducibility of cloud points of certain Diesel fuels.

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[7] *Proceedings*, Am. Soc. Testing Mats., Vol. 46, p. 337 (1946).

Subcommittee XVII on Plant Spray Oils (L. Mittelman, chairman).—Certain members of Subcommittee XVII are carrying out an informal investigation of the techniques of Methods D 447 - 41 and D 483 - 40 on the Distillation and Unsulfonated Residue of Plant Spray Oils, respectively, which will enable the subcommittee to recommend refinements in these methods which will provide greater reproducibility.

Subcommittee XIX on Illuminating Oils (E. W. Dean, chairman) is recommending that Method D 187 - 47 T, Test for Burning Quality of Kerosine, be adopted as standard again as no requests or suggestions for revision have been received. This method had previously been published as standard from 1927 to 1947, when it was reverted to tentative in order to provide suitable alternates for certain items of unobtainable equipment specified in this method.

Subcommittee XX on Nomenclature (S. S. Kurtz, Jr., chairman) is proposing four changes in the definitions covering a definition for "naphthenic acids" and a clarification of the currently overlapping terms "benzine," "petroleum ether," and "ligroine."

Subcommittee XXIII on Carbon Residue (F. I. L. Lawrence, chairman) is continuing its detailed study of the reproducibility and repeatability of the two carbon residue Methods, D 189 - 46, Test for Carbon Residue of Petroleum Products (Conradson Carbon Residue), and D 524 - 42, Test for Carbon Residue of Petroleum Products (Ramsbottom Carbon Residue), and of the correlation between the two.

Subcommittee XXIV on Petroleum Sulfonates (C. F. W. Gebelein, chairman) is continuing to study Method D 855 - 46 T, Analysis of Petroleum Sulfonates, for the purpose of improving its accuracy and of decreasing the potential hazard inherent in the currently used de-oiling solvent.

Subcommittee XXV (Research Division IV) on Analysis of Petroleum Products for Hydrocarbon Types (S. S. Kurtz, Jr., chairman):

Section A on Determination of Total Olefins Plus Aromatics by Acid Treating (S. S. Kurtz, Jr., chairman) is recommending the publication as tentative of the Proposed Method of Test for Total Olefinic Plus Aromatic Hydrocarbons in Petroleum Distillates. This method was published as information with the 1947 Report of Committee D-2.[6] This method was formerly part of Method D 875 - 46 T, and is of current use as a general method for quantitatively determining total olefins and aromatics in hydrocarbon mixtures.

Section B on Determination of Olefinic Unsaturation by Chemical Means (E. T. Scafe, chairman) has developed procedures for the determination of bromine number by colorimetric and electrometric methods which are being proposed for publication as information as they appear in Appendices X and XI. It is proposing the continuance of Method D 875 - 46 T, Test for Olefins and Aromatics in Petroleum Distillates until the acceptance of the methods for olefins plus aromatics and bromine number mentioned above.

Section C on Analysis of Hydrocarbons by Adsorption (L. Lykken, chairman) is recommending the revision and continuance as tentative of Method D 936 - 47 T, Test for Aromatic Hydrocarbons in Mixtures with Naphthenes and Paraffins by Adsorption with Silica Gel, as appended hereto.[4] Section C is also planning to carry out cooperative tests on a fluorescent indicator procedure for the rapid determination of aromatics.

Section D on Refractive Index, Dispersion, and Density (H. M. Smith, chairman) is proposing the adoption as standard of Method D 941 - 47 T, Test for Measurement of Density of Hydrocarbon Liquids by the Pycnometer. This method is a valuable procedure for hydrocarbon analysis which has been widely used and found reliable.

Section E on Determination of Purity by Freezing Point (F. D. Rossini, chairman) has revised Method D 940 - 47 T, Test for Determination of Purity by Measurement of Freezing Points, by splitting it into two separate methods: Test for Measurement of Freezing Points for Evaluation of Purity, and Test for Determination of Purity from Freezing Points. On the basis of this work, Subcommittee XXV has proposed the withdrawal of method D 940 - 47 T and the publication of these two new tentatives, as appended hereto.[5]

Section F on Spectroscopic Methods for the Analysis of Hydrocarbons (C. T. Shewell, chairman) is proposing the publication as tentative of the Proposed Method of Test for Benzene and Toluene by Means of Ultraviolet Spectrophotometry, which was published as information with the 1948 Report of Committee D-2.[1] It is also completing the preparation of a proposed Tentative Method of Test for Individual Hydrocarbons in C_4 Fractions (Spectrophotometric Method).

Section G on Determination of Hydrogen by the Lamp Method (R. Matteson, chairman) is proposing the publication as tentative of the Method of Test for Hydrogen in Petroleum Fractions by the Lamp Method, as appended hereto.[5] This method, which is useful in the calculation of heating values and hydrocarbon analysis, has proved to be a very convenient method for the determination of per cent hydrogen in volatile products, such as gasoline. Cooperative data have shown agreement within 0.05 per cent hydrogen.

Subcommittee XXV is recommending the withdrawal of Method D 481 - 39, Test for Acid Heat of Gasoline, on the basis that it is not a satisfactory measure of a significant property of gasoline.

Special Subcommittee on Extreme Pressure Properties Measurement (Harry Levin, chairman):

The initial work of this group, which will be restricted to oils, involves the cooperative testing by the methods currently employed in the laboratories of the cooperators.

RECOMMENDATIONS AFFECTING STANDARDS AND TENTATIVES

The proposals of the Technical Committees, Divisions, and Subcommittees, as outlined above, have been discussed in open meetings of Committee D-2 and have been submitted subsequently to letter ballot of the committee. The results of this ballot will be reported to the Society at the Annual Meeting.[7a] In no case did a proposal receive a negative vote of ten per cent or more. On the basis of these results, Committee D-2 makes the recommendations to the Society which are contained in the following sections.

Committee D-2 further proposes that these recommendations concerning the adoption of tentatives as standard and the revisions of standards for immediate adoption which are approved by the Society be referred to Sectional Committee Z11 for approval as American Standards.

[7a] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

PROPOSED METHODS TO BE PUBLISHED AS INFORMATION

Committee D-2 recommends that the following proposed methods of test be published as information, as appended hereto.[8]

- Appendix I. Test for Micro Cone Penetration of Lubricating Greases
- Appendix II. Test for Apparent Viscosity of Lubricating Greases
- Appendix III. Definitions, Functions, Types, and Designations of Cutting Fluids
- Appendix IV. Carburetor Jacket for Use with Motor and Research Methods to Rate High Vapor Pressure Fuels
- Appendix V. Test for Color Index of Petroleum Products by Photoelectric Colorimeter
- Appendix VI. Test for Sulfur in Petroleum Products by the CO_2 - O_2 Lamp Method with Supplement
- Appendix VII. Test for Boiling Point Range of Polymerization Grade Butadiene
- Appendix VIII. Test for Phosphorus in Lubricating Oils, Lubricating Oil Additives and Their Concentrates
- Appendix IX. Test for Bromine Number of Petroleum Distillates (Color Indicator Method)
- Appendix X. Test for Bromine Number of Petroleum Distillates (Electrometric Method)

NEW TENTATIVES

Committee D-2 recommends that the following twelve methods be accepted for publication as tentative.

Tentative Methods of Test for:[5]

- Acetylene in Polymerization Grade Butadiene by Silver Nitrate Method,
- Oxygen in Butadiene Vapors by Manganous Hydroxide Method,
- Peroxides in Butadiene by Ferrous Titanous Method,
- Separation of Residue from Butadiene,[1]
- Butadiene Dimer in Polymerization Grade Butadiene,[1]
- Nonvolatile Residue of Polymerization Grade Butadiene,[1]
- Sodium in Lubricating Oils and Lubricating Oil Additives,[1] with a change: Section 4 (*h*) to add the words "by warming" to the end of the first sentence; also to change the last sentence in Section 5 (*c*) to read: "If a precipitate forms, add 3 per cent hydrochloric acid until the precipitate just dissolves, or until the solution is pH 5, as indicated by the indicator paper."
- Measurement of Freezing Points for Evaluation of Purity,
- Determination of Purity from Freezing Points,
- Total Olefinic and Aromatic Hydrocarbons in Gasoline,[6]
- Hydrogen in Petroleum Fractions by the Lamp Method,
- Benzene and Toluene by Ultraviolet Spectrophotometry,[1] with the addition of the following new Section 13 on Precision:

13. Results should not differ from the mean by more than the following amounts:

Concentration Range of Benzene and Toluene, per cent by weight	**Repeatability** One Operator and Apparatus	**Reproducibility** Different Operators and Apparatus
0.5 to 2	0.05	0.10
2 to 10	0.10	0.25
10 to 15	0.20	0.40
15 to 20	0.25	0.50
20 to 25	0.30	0.60

REVISION OF TENTATIVES

Committee D-2 recommends revision of the following seven tentatives as indicated:

Tentative Specifications for:

D 439-48 T. Gasoline, revised as follows:

Table I.—In footnote *d* of this table, change the date from "1940" to "1949."

Tentative Methods of:

D 665-47 T. Test for Rust-Preventing Characteristics of Steam Turbine Oil in the Presence of Water, revised by changing "48 hr." to "24 hr." in Sections 2, 5 (*c*), and Note 6.

D 614-48 T. Test for Knock Characteristics, of Aviation Fuels by the Aviation Method,

D 908-48 T. Test for Knock Characteristics of Motor Fuels by the Research Method,

D 909-48 T. Test for Knock Characteristics of Aviation Fuels by the Supercharge Method,

In the above three methods, Section 5 requires the ASTM Knock Test Reference Fuels to conform to the specifications in Section 217 (*a*) of Supplement II of the A.S.T.M. Manual of Engine Test Methods for Rating Fuels.

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[8] See pp. 334 to 385

The following revision in Section 217 (*a*) is recommended:

Change the specification tolerances for density and refractive index of ASTM *iso*octane and *n*-heptane from "±0.00010" to "±0.00015."

D 937 – 47 T. Test for Penetration of Petrolatum, revised as appended hereto,[4]

D 936 – 47 T. Test for Aromatic Hydrocarbons in Olefin-Free Gasolines by Silica Gel Adsorption, revised as appended hereto.[4]

TENTATIVES CONTINUED WITHOUT REVISION

Committee D-2 recommends that the following eleven tentatives which have been published for two years or longer without revision be continued in their present status:

Tentative Methods of:

D 90 – 47 T. Test for Sulfur in Petroleum Products by the Lamp-Gravimetric Method,

D 96 – 47 T. Test for Water and Sediment in Petroleum Products by Means of Centrifuge,

D 155 – 45 T. Test for Color of Lubricating Oil and Petrolatum by Means of A.S.T.M. Union Colorimeter,

D 611 – 47 T. Test for Aniline Points and Mixed Aniline Points of Petroleum Products,

D 809 – 44 T. Chemical Analysis for Phosphorus in Lubricating Oils,

D 874 – 47 T. Test for Sulfated Residue from New Lubricating Oils,

D 875 – 46 T. Test for Olefins and Aromatics in Petroleum Distillates,

D 892 – 46 T. Test for Foaming Characteristics of Crankcase Oils,

D 939 – 47 T. Test for Saponification Number of Petroleum Products by Potentiometric Titration,

D 942 – 47 T. Test for Oxidation Stability of Lubricating Greases by the Oxygen Bomb Method, and

D 943 – 47 T. Test for Oxidation Characteristics of Inhibited Steam Turbine Oils.

WITHDRAWAL OF TENTATIVES

Committee D-2 recommends that the Tentative Method, D 894 – 48 T, Test for Sulfur in Lubricating Oils Containing Additives and in Additive Concentrates by Bomb Method be incorporated in Method D 129 – 44, Test for Sulfur in Petroleum Oils by Bomb Method, as recommended earlier in this report. It is recommended that Designation D 894 be discontinued.

Committee D-2 also recommends the withdrawal of Tentative Method D 940 – 47 T, Test for Determination of Purity by Measurement of Freezing Points, which is being replaced by the two new Tentative Methods of Test for Measurement of Freezing Points for Evaluation of Purity and Test for Determination of Purity from Freezing Points, as appended hereto.[5]

ADOPTION OF TENTATIVES AS STANDARD

Committee D-2 recommends that the following five tentatives be approved for reference to letter ballot of the Society for adoption as standard, four without revision and one with a revision as indicated:

Tentative Methods of:

D 187 – 47 T. Test for Burning Quality of Kerosine,

D 664 – 46 T. Test for Neutralization Value (Acid and Base Numbers) by Electrometric Titration,

D 873 – 46 T. Test for Oxidation Stability of Aviation Gasoline (Potential Gum Method), with Section 7 (*d*) revised to read as follows: "(*d*) If visible precipitate is present in the oxidized gasoline, filter the gasoline through a sintered-glass crucible of fine porosity and save the filtrate. Wash the interior of the liner twice with 10-ml. portions of solvent to remove any insoluble gum or precipitate. Filter the washings through the crucible, add them to the oxidized gasoline filtrate and mix them thoroughly. Reserve the mixture for determination of gum. Dry the crucible at 150 C. (302 F.) in an oven for 1 hr., cool in a covered vessel and weigh. Record any increase in weight as to quantity of visible precipitate."

D 938 – 47 T. Test for Congealing Point of Pharmaceutical Petrolatums, and

D 941 – 47 T. Measurement of Density of Hydrocarbon Liquids by the Pycnometer.

TENTATIVE REVISIONS OF STANDARDS

Committee D-2 recommends that the semi-micro Method for Oil Content of Paraffin Wax, as appended hereto,[5] be published as a tentative revision of

Standard Method D 721 - 47, Test for Oil Content of Paraffin Wax, with the view of its replacing the present text of Method D 721 within the next two years. The committee also recommends that the Tentative Method of Test for Free and Corrosive Sulfur in Petroleum Products, as appended hereto,[5] be published as a tentative revision of Standard Method D 130 - 30 which carries the same title.

REVISIONS OF STANDARDS, IMMEDIATE ADOPTION

Committee D-2 recommends for immediate adoption revisions in the following eight standards, and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these revisions may be referred to letter ballot of the Society:

Standard Methods of:

D 381 - 46. Test for Existent Gum in Gasoline (Air-Jet Evaporation Method), with a revision in the apparatus in Fig. 1 to include a straight-side beaker as shown in the accompanying Fig. 1.

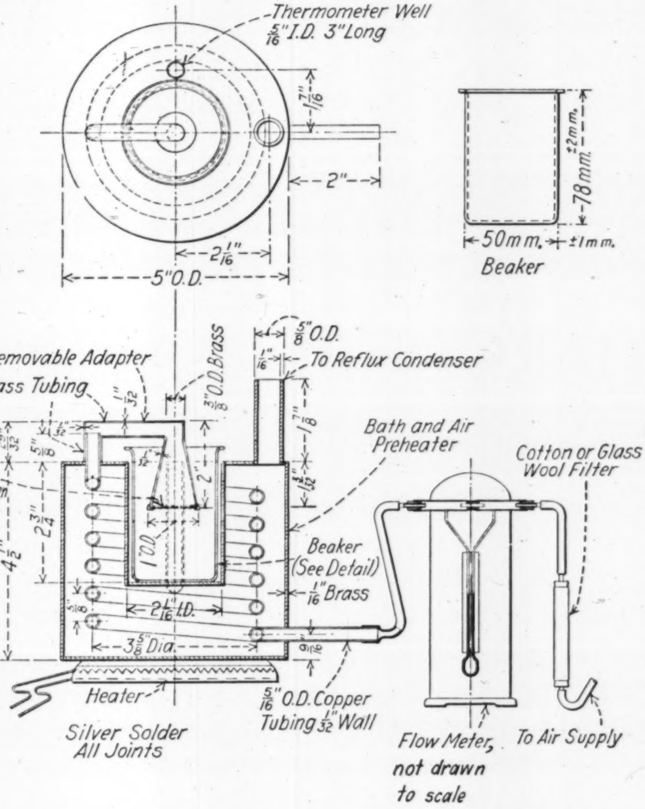
Thermometer Well
5/16" I.D. 3" Long
7/16"
2"
2 1/16"
5" O.D.
2mm.
78mm.
50mm.
1mm.
Beaker
5/8" O.D.
1/16"
To Reflux Condenser
Removable Adapter
3/8" O.D. Brass Tubing
1/32"
3/8" O.D. Brass
29/32"
5/8"
1/32"
1/32"
30-Mesh Copper Screen
2"
1 7/8"
1 3/32"
Bath and Air Preheater
Cotton or Glass Wool Filter
2 3/4"
4 1/2"
1" O.D.
Beaker (See Detail)
1/16" Brass
5/8"
2 1/16" I.D.
3 5/8" Dia.
9/16
Heater
5/16" O.D. Copper Tubing 1/32" Wall
Silver Solder All Joints
Flow Meter, not drawn to scale
To Air Supply

FIG. 1.—Apparatus for Determining Gum Content of Gasoline.

D 525 - 46. Test for Oxidation Stability of Gasoline (Induction Period Method), with a revised Fig. A2, in which the outside dimensions of the container are changed from "2 in." to "$1\frac{15}{16}$ in.," and the "V-shaped depressions 120 deg. apart" are to read "V-shaped depressions 120 deg. apart, one of which is depressed sufficiently to serve as a pouring lip."

D 323 - 43. Test for Vapor Pressure of Petroleum Products (Reid Method), revised as appended hereto.[4]

D 357 - 48. Test for Knock Characteristics of Motor Fuels by the Motor Method, with the same revision as recommended above for Tentative Methods D 614, D 908, and D 909.

D 127 - 30. Test for Melting Point of Petrolatum, revised as follows:

Title.—Change to read: "Standard Method of Test for Melting Point of Petrolatum and Microcrystalline Wax."

Section 1.—Change to read: "This method of test is intended for the determination of the A.S.T.M. melting point of petrolatum and microcrystalline wax."

The note to this section remains unchanged.

Section 3 (c).—Change to read: "(*c*) *Thermometer.*—An A.S.T.M. Petrolatum Melting Point Thermometer graduated in either Centigrade or Fahrenheit degrees as specified, having a range of 32 to 127 C. or 90 to 260 F. and conforming to the requirements for this thermometer as prescribed in Standard E 1, Specifications for A.S.T.M. Thermometers.

Section 4 (a).—Change the second sentence to read: "The material shall be melted slowly, while stirring, in a casserole or other suitable dish until the temperature reaches 200 F. or 15 F. above the expected melting point, whichever is higher."

D 156 - 38. Test for Color of Refined Petroleum Oil by Means of Saybolt Chromometer, revised as follows:

New Sections.—Add the following new Sections 3 and 5, renumbering the present Section 3 on Procedure as Section 4:

3. *Sample.*—If the sample is not clear, filter through a sufficient number of rapid qualitative filter papers (Whatman No. 4 or equivalent) before testing.

5. *Reporting.*—If the sample has been filtered, report as Saybolt color (sample filtered).

D 129 - 44. Test for Sulfur in Petroleum Oils by Bomb Method, revised by the incorporation of Method D 894 and changes in Scope and Sections 3, 4, and 5, as appended hereto.[4]

D 288 - 48. Definitions of Terms Relating to Petroleum, revised as follows:

Benzine.—Add the following note after this definition: "Note.—The term 'petroleum benzin' has appeared in the U. S. Pharmacopoeia for many years designating a refined light naphtha used for extraction purposes. This term should only be used for material meeting the U. S. Pharmacopoeia specifications. The term 'benzin' should never be used without the prefix 'petroleum'."

Add the following new definitions in the appropriate alphabetical order:

Ligroine.—A saturated petroleum naphtha boiling in the range 20 to 135 C. (68 to 275 F.) and suitable for general laboratory use.

NOTE.—This term should be used in place of "benzine" or "petroleum ether."

Naphthenic Acids.—Naphthenic acids are carboxylic acid derivatives of cycloalkane hydrocarbons (naphthenes). The monobasic acids have the general type formula $C_nH_{2n-2x}O_2$ where x is the number of rings in the molecule.

Petroleum Ether.—This term is misleading and should not be used. See Ligroine.

REAFFIRMATION OF STANDARDS

Committee D-2 recommends the reaffirmation of the following 22 standards which have been published for six years or longer without revision:

Standard Specifications for:

D 484 - 40. Stoddard Solvent.

Standard Methods of:

D 56 - 36. Test for Flash Point by Means of the Tag Closed Tester,

D 87 - 42. Test for Melting Point of Paraffin Wax,

D 91 - 40. Test for Precipitation Number of Lubricating Oils,

D 157 - 36. Test for Steam Emulsion of Lubricating Oils,

D 158 - 41. Test for Distillation of Gas Oil and Similar Distillate Fuel Oils,

D 206 - 36. Abridged Volume Correction Table for Petroleum Oils,

D 216 - 40. Test for Distillation of Natural Gasoline,

D 219 - 36. Test for Burning Quality of Long-Time Burning Oil for Railway Use,

D 239 - 30. Test for Burning Quality of Mineral Seal Oil,

D 240 - 39. Test for Thermal Value of Fuel Oil,

D 285 - 41. Test for Distillation of Crude Petroleum,

D 286 - 30. Test for Autogenous Ignition Temperatures of Petroleum Products,

D 287 - 39. Test for Gravity of Petroleum and Petroleum Products by Means of the Hydrometer,

D 322 - 35. Test for Dilution of Crankcase Oils,

D 341 - 43. Standard Viscosity-Temperature Charts for Liquid Petroleum Products,

D 446 - 39. Conversion of Kinematic Viscosity to Saybolt Universal Viscosity,

D 447 - 41. Test for Distillation of Plant Spray Oils,
D 483 - 40. Test for Unsulfonated Residue of Plant Spray Oils,
D 524 - 42. Test for Carbon Residue of Petroleum Products (Ramsbottom Carbon Residue),
D 566 - 42. Test for Dropping Point of Lubricating Grease, and
D 567 - 41. Calculating Viscosity Index.

WITHDRAWAL OF STANDARD

Committee D-2 recommends the withdrawal of Standard Method D 481 - 39, Test for Acid Heat of Gasoline.

MISCELLANEOUS RECOMMENDATIONS

Committee D-2 recommends that general approval be given to the publication of an A.S.T.M. Manual on Measuring and Sampling Petroleum and its Products. This manual will be separate from the compilation of A.S.T.M. Standards on Petroleum Products and Lubricants and will include all methods which come under this general heading which have been prepared under the sponsorship of the committee.

This report has been submitted to letter ballot of Committee D-2 which consists of 100 voting members; 61 members returned their ballots, of whom 57 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

C. DANTSIZEN,
Chairman.

W. T. GUNN,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-2 presented to the Society through the Administrative Committee on Standards the recommendation that the Tentative Method of Test for Chlorine in Lubricaing Oils by Bomb Method (D 808 - 44 T) be revised.

This recommendation was accepted by the Standards Committee on September 22, 1949, and the revised tentative appears in the 1949 Book of A.S.T.M. Standards, Part 5.

APPENDIX I

PROPOSED METHOD OF TEST FOR THE DETERMINATION OF MICRO CONE PENETRATION OF LUBRICATING GREASE[1]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Scope

1. (*a*) This method describes a procedure for the measurement of the unworked (Note 1) and worked penetration of lubricating greases as an empirical measure of consistency where the quantity of grease available is too small for consistency measurements by A.S.T.M. Method D 217, test for Cone Penetration of Lubricating Grease.[2] The test is applicable to greases having micro penetrations up to 200.[3]

NOTE 1.—Although this method is intended primarily for penetration tests on very small samples, the procedure for worked penetration is included since a comparison of the worked consistency of the unused grease with the consistency of small fractions of grease, obtained from different locations on test devices employing ball or roller bearings, is sometimes desired.

(*b*) Unworked penetrations are affected by a number of factors which are difficult to control (Note 2), and do not generally represent the consistency of grease in use as effectively as worked penetrations which should therefore be preferred for evaluating lubricating grease, wherever practicable.

NOTE 2.—The unworked penetration of a grease may not be a reliable measure of its consistency in its original state of manufacture. Any transferring or other manipulating of grease subsequent to manufacture tends to affect the unworked penetration by amounts depending on the type of the grease and the handling it is given.

2. (*a*) *Micro Penetration* of lubricating grease is the depth, in tenths of a millimeter, that a standard micro cone penetrates the sample.

(*b*) *Working* is the altering of the penetration of a grease by subjecting it to any form of agitation or shearing action for a significant period.

(*c*) *Worked Micro Penetration* is the micro penetration of a sample of lubricating grease immediately after transferring it to the micro test cup from the standard grease worker where it had been brought to 77 F. and subjected to 60 strokes of the worker.

(*d*) *Unworked Micro Penetration* is the micro penetration at 77 F. of a sample of lubricating grease which has received only the minimum handling in transfer from sample cone to micro test cup and which has not been subjected to the action of the grease worker.

Outline of Method

3. The penetration is determined at 77 F. using a penetrometer to apply the standard micro cone to the sample in a

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[1] This proposed method is under the jurisdiction of the A.S.T.M. Committee D-2 on Petroleum Products and Lubricants Published as information, June, 1949.

[2] 1949 Book of A.S.T.M. Standards, Part 5.

[3] For a comparison of results with the standard cone of A.S.T M. Method D 217, see "Micro Penetration of Lubricating Grease," ASTM BULLETIN, No. 147, August, 1947, p. 81.

micro cup for 5 sec. Unworked micro penetrations are determined on the sample as received. Worked micro penetrations are determined immediately after subjecting the sample to 60 strokes in the standard grease worker.

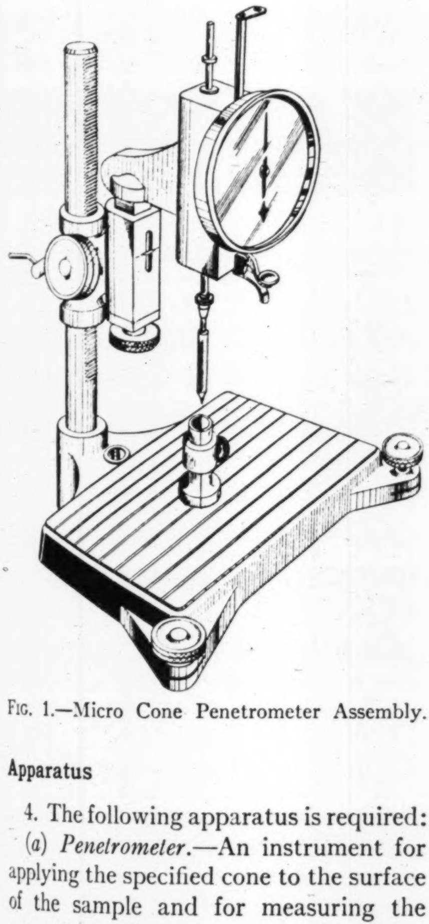

FIG. 1.—Micro Cone Penetrometer Assembly.

Apparatus

4. The following apparatus is required:

(*a*) *Penetrometer.*—An instrument for applying the specified cone to the surface of the sample and for measuring the penetration distance at the conclusion of the test. It shall be so constructed that it permits (by means of a slow-motion adjustment) the accurate placement of the tip of the cone at the level surface of the sample while maintaining a "zero" reading on the indicator, and so that it permits the cone to fall, when released, without appreciable friction. The instrument shall be provided with leveling screws and a spirit level to maintain the cone shaft in a true vertical position. A simplified sketch of such a penetrometer with cone attached is shown in Fig. 1.

(*b*) *Micro Cone* and *Grease Cup* constructed as described in detail in the Supplement.

(*c*) *Grease Worker*, for manual or motor operation, constructed as described in detail in the Appendix to A.S.T.M. Method D 217.[2]

(*d*) *Constant-Temperature Bath.*—A constant-temperature testing room or an air bath capable of regulation to 77 ± 1 F.

(*e*) *Spatula.*—A spatula, of corrosion-resistant steel, having a stiff blade 1.25 in. in width and at least 6 in. in length with its end cut on the square.

Procedure for Unworked Micro Penetration

5. (*a*) *Sample.*—A sample of grease of approximately 4 g. is required to fill the grease cup. However, a smaller amount may be evaluated, if the grease is not too soft, by using wooden plugs to fill the lower part of the cup.

(*b*) *Preparation of Sample for Measurement.*—Place the sample and grease cup in the air bath and bring to 77 ± 1 F. Then transfer the grease to the grease cup by means of a spatula, filling each half of the split cylinder and taking care that air pockets are avoided. Then clamp the two halves together by means of the brass collar as shown in Fig. 1. Replace the grease cup in the air bath for a sufficient time (approximately 20 min.) to compensate for any slight change in temperature during the filling period. Scrape off the excess grease above the rim of the cup by moving the blade of the spatula, held inclined toward the direction of motion at an angle of 45 deg., across the rim of the cup.

(*c*) *Penetration Measurement.*—Place the cup on the penetrometer table. Make certain that the cone is in its "zero" position, and lower the cone and indicator assembly as a unit until the cone tip nearly touches the surface of the sample at a point as close as possible to the center of the cup. Securely lock the cone and indicator assembly and bring the cone tip down to just touch the surface of the sample by means of the slow-motion adjustment (Note 3). Operating the release mechanism rapidly, release the cone shaft and hold it free for 5 ± 1 sec. timing this interval with a stopwatch registering to 0.1 sec. (Note 4). Make certain that the release mechanism does not drag on the shaft. Then gently depress the indicator shaft until it is stopped by the cone shaft and read the penetration from the indicator scale.

NOTE 3.—When using a penetrometer which has a fixed indicator assembly and adjustable table, modify the above detailed procedure to suit the instrument.

NOTE 4.—The timing can be done conveniently by starting the watch before beginning the test, releasing the cone shaft as the second hand crosses a unit graduation on the watch, and engaging the shaft of the cone when the watch indicates 5 ± 0.1 sec. later.

(*d*) *Cleaning Cone.*—Following each test, clean the penetrometer cone by wiping it carefully with a clean cloth while holding it securely in its raised position (to avoid bending its shaft). Rotating the cone is to be discouraged, as it may cause wear on the release mechanism.

(*e*) *Additional Tests.*—Make a total of three tests on fresh portions of sample, and report the average value, to the nearest 0.1 mm. as the unworked micro penetration of the sample.

NOTE 5.—If insufficient sample is available for the second and third tests, another penetration may be made on the sample in the grease cup.

Procedure for Worked Micro Penetration

6. (*a*) *Sample.*—Sufficient sample (at least 1 lb.) to overfill the cup of the standard grease worker is required.

(*b*) *Working.*—Transfer sufficient sample to the cup of the clean grease worker to fill it heaping full (mounted up about 0.5 in. at the center), avoiding the occlusion of air by packing with the spatula. Assemble the worker, and with the vent cock open, depress the plunger to the bottom. Insert the dial thermometer through the vent cock so that its tip is in the center of the grease. Place the assembled worker, and the grease cup in the 77 F. air bath until the temperature of the worker, its contents, and the grease cup is 77 ± 1 F. Then remove the worker from the bath, remove the thermometer and close the vent cock. Subject the grease to 60 full double strokes of the plunger, completed in about 1 min., and return the plunger to its top position. Open the vent cock and remove the top and plunger. As the penetration of a worked lubricating grease may change significantly on standing it is imperative that the operations described in Paragraphs (*c*) to (*f*) be performed without delay.

(*c*) *Transfer to Grease Cup.*—By means of a spatula transfer the worked grease to the small grease holder, filling each half of the split cylinder and taking care that air pockets are avoided. Then clamp the two halves together by means of the brass collar as indicated in Fig. 1. Replace the grease cup in the bath for a sufficient time (approximately 20 min.) to compensate for any slight change in temperature during the filling period. Scrape off the excess grease extending above the brim of the cup by moving the blade of the spatula, held inclined toward the direction of motion at an angle of 45 deg., across the brim of the cup.

(*d*) *Penetration Measurement.*—Determine the penetration of the sample as described in Section 5 (c).

(*e*) *Cleaning Cone.*—Following each test, clean the penetrometer cone as described in Section 5(*d*).

(*f*) *Additional Tests.*—Immediately make two more tests in succession on the same worked sample by adding a new supply of grease to the grease cup and repeating the test as described in Paragraphs (*c*) to (*e*). Report the average of the three tests to the nearest 0.1 mm. as the worked micro penetration of the sample.

Precision

7. Results should not differ from the mean by more than the following amounts:

	Repeatability One Operator and Apparatus	**Reproducibility** Different Operators and Apparatus
Worked micro penetration..	4 units	7 units
Unworked micro penetration	4 units	7 units

SUPPLEMENT

APPARATUS

A1. *Micro Cone,* aluminum, consisting of a cone, plunger with collars and locknut conforming to the dimensions shown in Fig. 2. The outer surface of the cone and tip shall be given a very smooth finish. The weight of the cone shall be 5 ± 0.1 g. The combined weight of the plunger and locknut shall be 15 ± 0.1 g.

A2. *Grease Cup,* consisting of a split brass bushing affixed to suitable base and a brass collar with set screw for holding the two halves together as shown in Fig. 2. This grease cup has a capacity of approximately 4 g. of grease but smaller amounts can be evaluated, if the grease is not too soft, by using wooden plugs to fill the lower part of the cup.

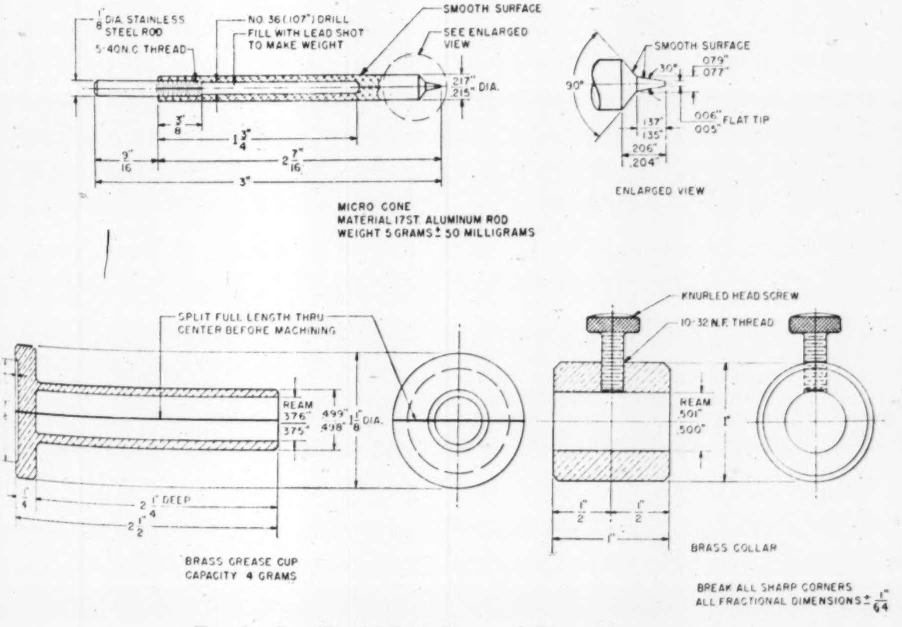
1/8" DIA. STAINLESS STEEL ROD
5-40N.C THREAD
NO 36 (.107") DRILL
FILL WITH LEAD SHOT TO MAKE WEIGHT
SMOOTH SURFACE
SEE ENLARGED VIEW
.217"
.215" DIA.
3/8"
1 3/4"
9/16"
2 7/16"
3"
MICRO CONE
MATERIAL 17ST. ALUMINUM ROD
WEIGHT 5 GRAMS ± 50 MILLIGRAMS
SMOOTH SURFACE
90°
30°
.079"
.077"
.006"
.005" FLAT TIP
.137"
.135"
.206"
.204"
ENLARGED VIEW
SPLIT FULL LENGTH THRU CENTER BEFORE MACHINING
REAM
.376"
.375"
.499"
.498"
1 1/8" DIA.
1/4"
2 1/4" DEEP
2 1/2"
BRASS GREASE CUP
CAPACITY 4 GRAMS
KNURLED HEAD SCREW
10-32 N.F. THREAD
REAM
.501"
.500"
1"
1/2"
1/2"
1"
BRASS COLLAR
BREAK ALL SHARP CORNERS
ALL FRACTIONAL DIMENSIONS ± 1/64"

FIG. 2.—Details of Micro Cone and Grease Cup.

APPENDIX II

PROPOSED METHOD OF TEST FOR APPARENT VISCOSITY OF LUBRICATING GREASES[1]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Scope

1. This method of test describes a procedure for measuring, in poises, the apparent viscosity of lubricating grease at room temperature (Note 1). The technique described is applicable to all greases, but the apparatus described is limited to measurements in the range of 25 to 60,000 poises at ten reciprocal seconds and 1 to 100 poises at 15,000 reciprocal seconds.

Note 1.—By enclosing the apparatus in a suitably thermostated cabinet or bath it may be used for apparent viscosity measurements over a wide range of temperature, but equipment for this extended use is not yet subject to standardization.

Terminology

2. (*a*) *Apparent Viscosity.*—The apparent viscosity of a lubricating grease is the ratio of shear stress to shear rate calculated from Poiseuille's equation and is measured in poises. Since greases are not Newtonian, the ratio will vary with shear rate (See Section 7(*a*)).

(*b*) *Capillary.*—For the purpose of this method a capillary is any right cylindrical tube having a length to diameter ratio of 40 to 1.

(*c*) *Shear Rate.*—Shear rate is the rate at which a series of adjacent layers of grease move with respect to each other. It is proportional to the linear velocity of flow divided by the capillary radius and is thus expressed as reciprocal seconds.

(*d*) *Yield Value.*—Yield value is the minimum force required to produce flow. It is indicated by the intercept on the shear stress axis of the prolongation of the straight portion of the curve of shear stress *versus* shear rate.

Outline of Method

3. The sample is forced through a capillary by means of a floating piston actuated by the hydraulic system. From the predetermined flow rate and the force developed in the system the apparent viscosity is calculated by means of Poiseuille's equation. A series of eight capillaries and two pump speeds are used to determine the apparent viscosity at sixteen shear rates. The results are expressed as a log-log plot of apparent viscosity *versus* shear rate.

Apparatus

4. The assembled pressure viscometer consists of three major divisions, the power system, the hydraulic system, and the grease system as described in the Supplement and shown in Fig. 1. A photograph of such an assembly is shown Fig. 2.

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[1] This proposed method is under the jurisdiction of the A.S.T.M. Committee D-2 on Petroleum Products and Lubricants. Published as information, June, 1949.

Sample

5. (*a*) A single filling of the grease cylinder requires about ½ lb. of grease which is the minimum size sample (Note 2).

(*b*) Generally no special preparation of the sample is necessary (Notes 3 and 4).

NOTE 2.—It is possible for an experienced operator to complete the 16 single determinations with a single filling. However, some samples reach the equilibrium pressure slowly making it advisable to have a sample of several pounds available.

NOTE 3.—The apparatus "works" the sample to some extent as it passes through the capillary. Somewhat better reproducibility is obtained on some products if they are previously worked as described in A.S.T.M. Method D 217, Test for Cone Penetration of Lubricating Grease.[2]

NOTE 4.—It is desirable to filter some greases to prevent plugging the No. 8 capillary.

Standardization

6. (*a*) To calibrate the hydraulic system, remove the grease cylinder and replace it with a ¼-in. copper tube or pipet approximately 2 in. long. Select an hydraulic oil of about 2,000 centistokes at the test temperature. Fill the system with hydraulic oil and circulate the oil until it is free of air bubbles. With the pump operating, quickly place a 60-ml. Saybolt receiving flask (A.S.T.M. Method D 88)[3] under the outlet and simultaneously start the timer. Determine the delivery time for 60 ml. and calculate the flow rate in cubic centimeters per second assuming 1 ml. equal to 1 cc. Repeat this measurement for each gear ratio used. If pressures over 1000 psi. are used regularly in the grease viscosity measurement, calibrate the delivery as above using a needle valve in place of

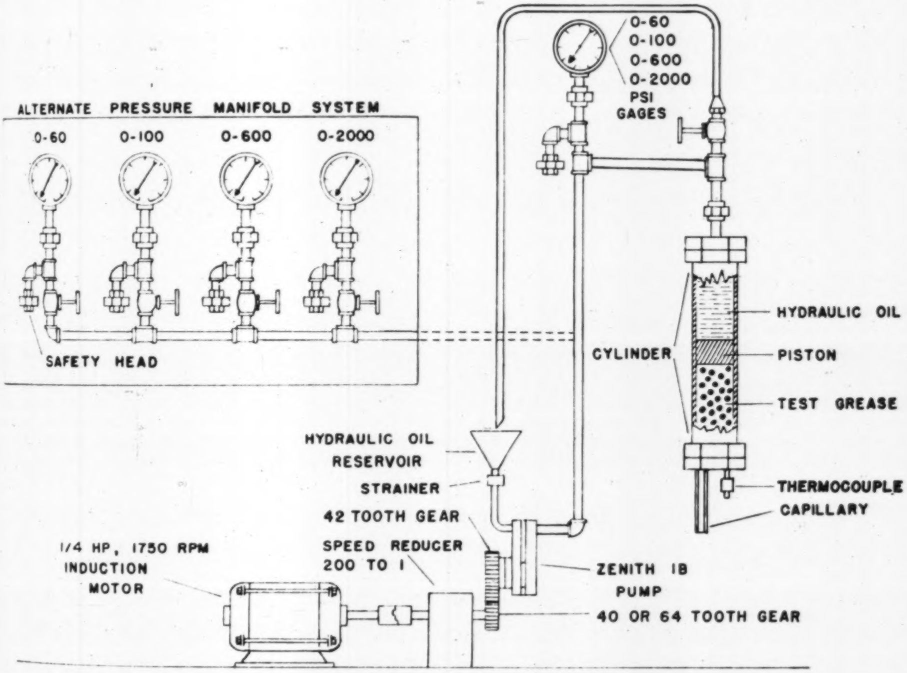
0-60
0-100
0-600
0-2000
PSI
GAGES
ALTERNATE PRESSURE MANIFOLD SYSTEM
0-60
0-100
0-600
0-2000
SAFETY HEAD
HYDRAULIC OIL
CYLINDER
PISTON
TEST GREASE
HYDRAULIC OIL
RESERVOIR
STRAINER
42 TOOTH GEAR
SPEED REDUCER
200 TO 1
THERMOCOUPLE
CAPILLARY
1/4 HP, 1750 RPM
INDUCTION
MOTOR
ZENITH IB
PUMP
40 OR 64 TOOTH GEAR

FIG. 1.—Schematic Drawing of Apparatus.

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[2] 1949 Book of A.S.T.M. Standards, Part 5.

[3] See Standard Method of Test for Viscosity by Means of the Saybolt Viscosimeter (A.S.T.M. Designation: D 88), 1949 Book of A.S.T.M. Standards, Part 5.

the orifice tube and adjust it until the gage reads approximately 1500 lb. before filling the Saybolt receiving flask. Repeat the calibration at regular intervals to determine if wear is changing the pump flow.

(*b*) To calibrate the capillary, measure the length to the nearest 0.001 in. by means of a micrometer. Close one end of the capillary, flush with the end, and fill it with mercury. The smallest capillaries may cause difficulty during the mercury filling operation; this may be minimized by drawing out a glass tube one end of which can be inserted into the capillary. Drain the mercury into a tared beaker and weigh to the nearest milligram. Calculate the volume by dividing the weight by the density of mercury at the temperature used. Calculate the radius in centimeters.

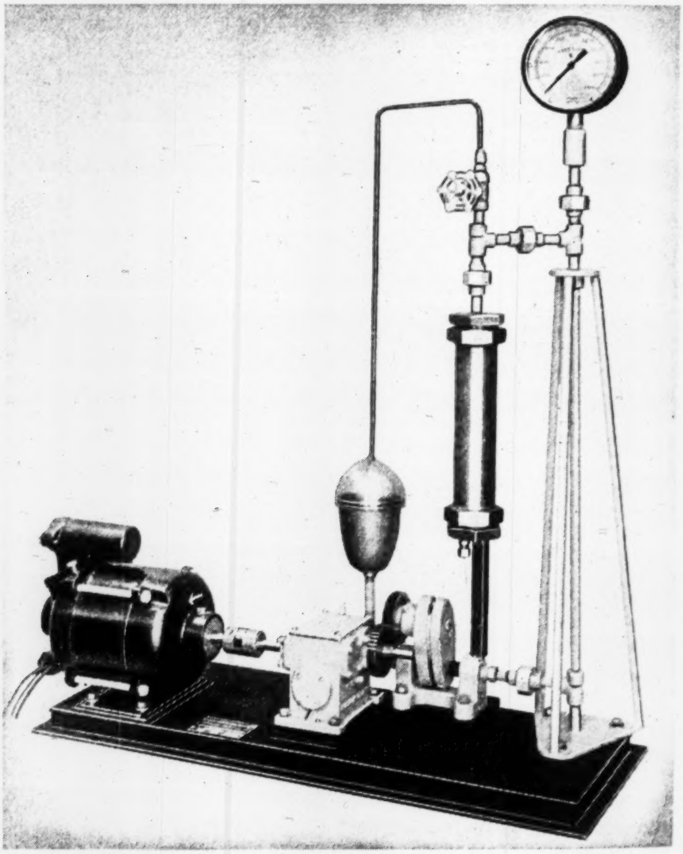

FIG. 2.—Photograph of Apparatus.

(*c*) An alternate calibration method that may be used to check the small capillary radius consists of using an oil of known viscosity in place of the grease sample and following the procedure described in Section 7. Calculate the radius as follows:

$$R = \frac{(8L\eta v/t)^{1/4}}{\pi P 68944} = \frac{(L\eta v/t)^{1/4}}{27074P}$$

where:

η = viscosity of oil used at test temperature,

v/t = flow rate in milliliters per second, determined in pump calibration,

L = capillary length in centimeters, and

P = gage pressure in pounds per square inch.

TABLE I.—SUGGESTED DATA SHEET FOR RECORDING TEST RESULTS. (WITH ILLUSTRATIVE TEST VALUES.)

Sample....*No. 2 Grease* Temperature....*77 F.*
Date......*November 1, 1948* Operator.......*R. S.*

1	2	3	4[a]	5[b]	6[a]	7[c]
Capillary	Gear	Observed Pressure, P, psi.	$K = \frac{68944\ \pi R^4}{8\ L\ v/t}$	Apparent Viscosity, η, poises $= P \times K$	Shear Rate, S, sec.$^{-1}$ $= \frac{4\ v/t}{\pi R^3}$	Shear Force, dynes per sq. cm. $= \eta \times S$
1.....	40...	25.5	28.10	716	15	10 740
2.....	40...	38.3	6.83	267	61	16 300
3.....	40...	48.8	3.61	176	120	21 100
4.....	40...	63.5	1.90	120	230	27 800
5.....	40...	96.5	0.89	86	480	41 300
6.....	40...	125	0.58	72.6	755	54 800
7.....	40...	286	0.139	39.8	3140	125 000
8.....	40...	546	0.0464	25.3	9320	235 500
1.....	64...	29.5	17.60	520	24	12 470
2.....	64...	45.8	4.27	195	98	19 100
3.....	64...	60	2.26	135.5	195	26 400
4.....	64...	82.3	1.19	97.9	370	36 250
5.....	64...	130	0.556	72.4	770	55 800
6.....	64...	165	0.363	59.9	1220	73 200
7.....	64...	384	0.087	33.4	5020	167 500
8.....	64...	720	0.029	20.9	14900	311 000

[a] Values in this column are predetermined.
[b] Column 3 times column 4.
[c] Column 5 times column 6.

Procedure

7. (*a*) Charge the sample so as to reduce inclusion of air to a minimum. Soft greases may be poured into the cylinder or drawn up by vacuum; heavy samples must be hand packed. When filling the cylinder by vacuum, the capillary end cap is removed and the piston placed flush with the open end which is then inserted into the sample. Vacuum is applied to the opposite end of the cylinder until the cylinder is fully charged with grease. This must be facilitated by tapping with a wooden block. Replace the capillary end cap and fill the upper end of the cylinder above the piston with hydraulic oil.

(*b*) Fill the entire hydraulic system with hydraulic oil. Disconnect, invert, and fill the gage and gage connections with oil. With the entire hydraulic system connected and completely filled with oil, adjust the temperature of the sample

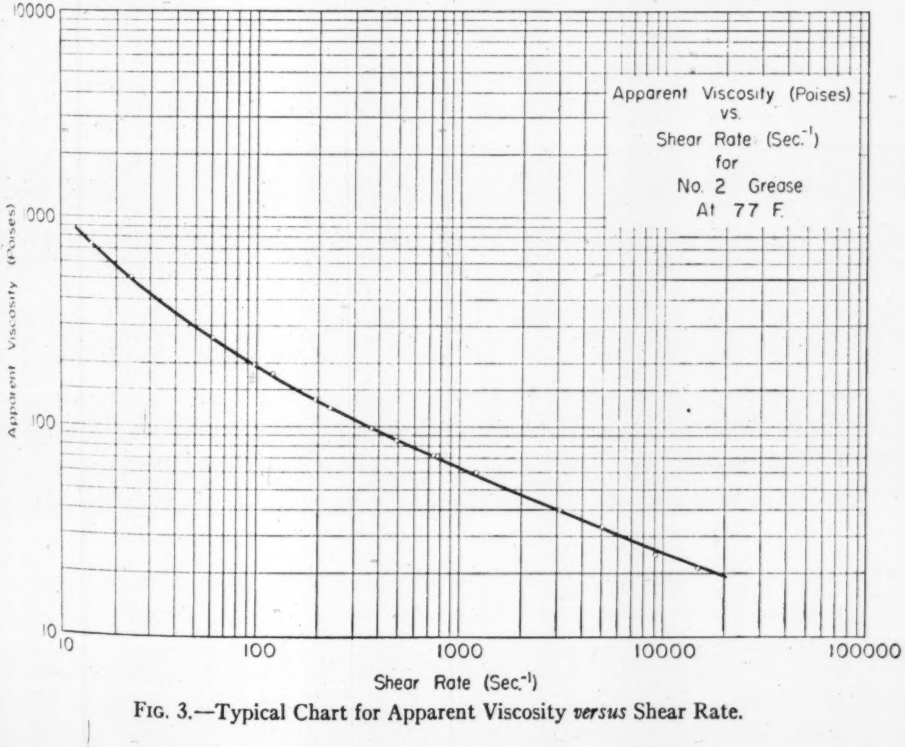

FIG. 3.—Typical Chart for Apparent Viscosity *versus* Shear Rate.

to 77 ± 0.5 F. as determined by a thermocouple inserted in the capillary end cap. Operate the pump until oil flows from the gage connection on the viscometer before reconnecting the gage. With the entire viscometer assembled, circulate hydraulic oil with the return valve open until all trace of air is eliminated.

(*c*) With No. 1 capillary in place and the 40-tooth gear connected, operate the pump with the return valve closed until equilibrium pressure is obtained. Record the pressure. Change to the 64-tooth gear and again establish equilibrium. Record and relieve the pressure. Replace the No. 1 capillary with No. 2 and repeat these operations, repeat until each capillary has been used with both flow rates (Note 5).

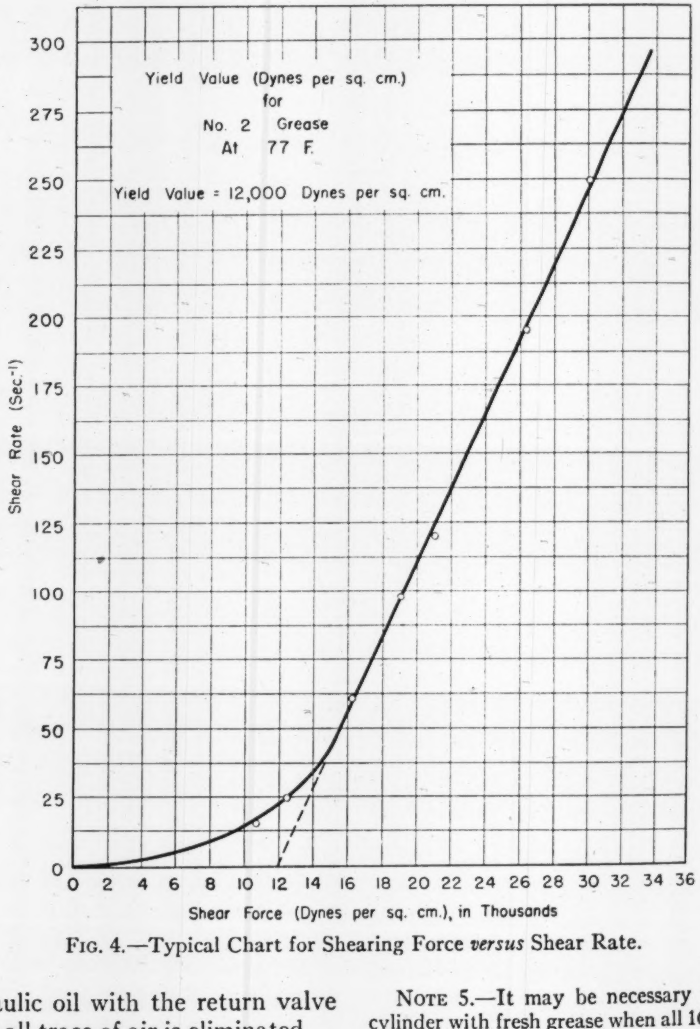

FIG. 4.—Typical Chart for Shearing Force *versus* Shear Rate.

NOTE 5.—It may be necessary to refill the cylinder with fresh grease when all 16 determinations are made.

Calculations

8. (*a*) Calculate apparent viscosity of the grease as follows:

$$\eta \text{ (apparent viscosity)} = \frac{F}{S}$$

where: F is the shear stress and S is the shear rate. Therefore:

$$\eta = \frac{F}{S} = \frac{\dfrac{P\pi R^2}{2\pi RL}}{\dfrac{4v/t}{\pi R^3}} = \frac{P\pi R^4}{8Lv/t} = \frac{P68944\pi R^4}{8Lv/t}$$

where:

P = observed pressure, and 68944 is used to convert pounds per square inch to dynes per square centimeter,

R = radius of capillary used in centimeters, and

v/t = flow rate in milliliters per second.

(*b*) Calculations may be reduced to a minimum by preparing a table of 16 constants, one for each capillary and shear rate (see Table I). For example, viscosity with No. 1 capillary and the 40-tooth gear is given by the formula:

$$\eta = \frac{P \text{ (observed) } 68944\pi R^4}{8Lv/t} \quad \text{or} \quad PK_{(1-40)}$$

(*c*) Also calculate the shear rates as follows:

$$S = \frac{4v/t}{\pi R^3}$$

Sixteen rates shall be calculated for the eight capillaries and two flow rates. This calculation need not be repeated for each run since it will remain constant until recalibration of the pump indicates a revision.

(*d*) Plot a curve of apparent viscosity *versus* shear rate on log-log paper, as shown in Fig. 3.

(*e*) Plot a curve using the shearing force, $\frac{PR}{2L}$, as the abcissa and the shear rate, $\frac{4\,v/t}{\pi R^2}$, as the ordinate and extend the straight portion to estimate the yield value as illustrated in Fig. 4.

SUPPLEMENT

APPARATUS FOR GREASE SYSTEM

A1. *Apparatus*, The assembled pressure viscometer apparatus[4] consists of three major parts, the power system, the hydraulic system and the viscometer system as shown in Figs. 1 and 2 and constructed as described in Paragraphs A2 to A6.

A2. *Power System* consisting of a $\frac{1}{3}$ hp., 1750 rpm. induction motor coupled to a 200 to 1 speed reducer. Interchangeable 40 and 64 tooth gears are used to drive the hydraulic pump.

A3. *Hydraulic System* consisting of a gear pump fitted with saddle mount and 42 tooth drive gear;[5] a hydraulic oil reservoir having a capacity at least equal to the grease cylinder and fitted with a 50-mesh screen shall be provided. The pump and grease cylinder shall be connected with high pressure valves and fittings as shown in Fig. 1. Means shall be provided for connecting interchangeable test gages.

A4. *Gages.*—Since the gages are used only in the middle range several are desirable to cover a wide variety of greases. Four gages having ranges of 0 to 60, 0 to 100, 0 to 600, and 0 to 2000 lb. have been found suitable. Alternately, the gages may be manifolded provided proper means of eliminating air from the system is employed (See Fig. 1).

A5. *Grease Cylinder Assembly* consisting of cylinder, floating piston and caps constructed to conform to the tolerances shown in Fig. 5 with the piston moving the entire length of the cylinder without appreciable friction. The cylinder shall be constructed to withstand a working pressure of 2000 psi. The exterior features and method of fastening may be modified.

A6. *Capillaries*, eight of stainless steel and conforming to dimensions shown in Fig. 6 shall comprise a set; critical dimensions are the interior radius and length. It is essential that the radius of each be approximately that shown in Fig. 6 and that the length be 40 times the actual diameter. Exterior features of the mounting may be modified, provided proper protection and connection to the grease cylinder cap are provided.

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[4] The assembled apparatus is available from the Precision Scientific Co., Catalog No. 74911.

[5] Zenith 1B, QE pump as manufactured by Zenith Products, West Newton, Mass., is satisfactory. Type B-4416H is available for high temperature, type B-4408 for high pressure.

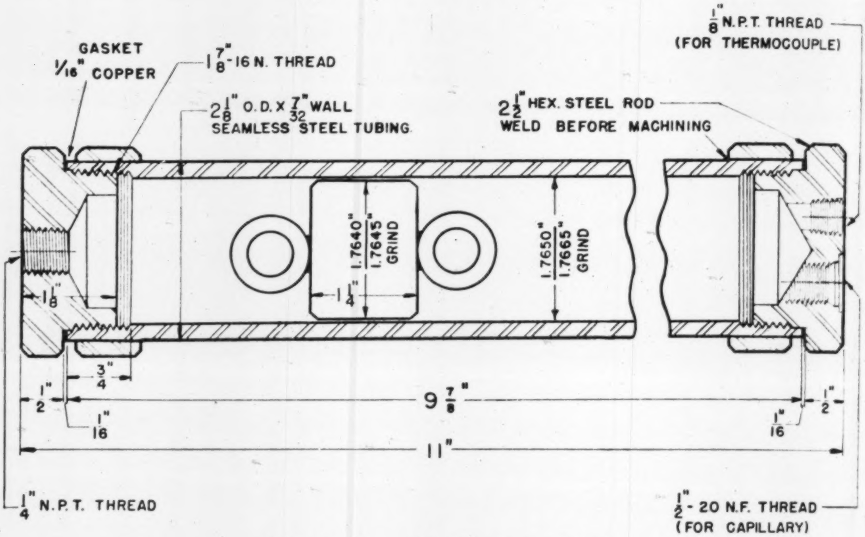
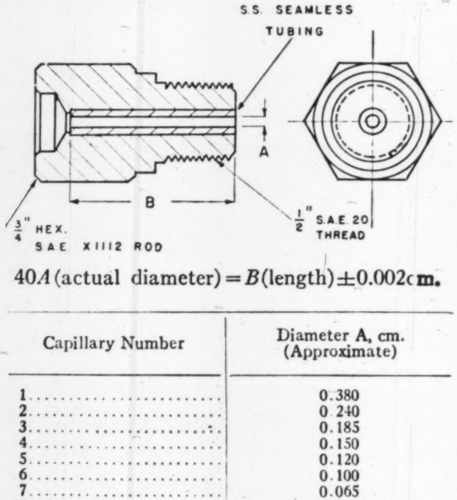

1/8" N.P.T. THREAD (FOR THERMOCOUPLE)
GASKET 1/16" COPPER
1 7/8"-16 N. THREAD
2 1/8" O.D. X 7/32" WALL SEAMLESS STEEL TUBING
2 1/2" HEX. STEEL ROD WELD BEFORE MACHINING
1.7640" 1.7645" GRIND
1 1/4"
1.7650" 1.7665" GRIND
1 1/8"
3/4"
1/2"
9 7/8"
1/16"
1/16"
1/2"
11"
1/4" N.P.T. THREAD
1/2"-20 N.F. THREAD (FOR CAPILLARY)

FIG. 5.—Grease Cylinder Assembly.


S.S. SEAMLESS TUBING
A
B
3/4" HEX. S.A.E. X1112 ROD
1/2" S.A.E. 20 THREAD

$40A$ (actual diameter) $= B$ (length) ± 0.002 cm.

Capillary Number	Diameter A, cm. (Approximate)
1	0.380
2	0.240
3	0.185
4	0.150
5	0.120
6	0.100
7	0.065
8	0.045

FIG. 6.—Capillary Construction.

APPENDIX III

PROPOSED DEFINITIONS, FUNCTIONS, TYPES, AND DESIGNATIONS OF CUTTING FLUIDS[1]

These proposed definitions are published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

DEFINITION

Cutting Fluid (Coolant, Lubricant, etc., applied to cutting tools).—Any substance applied to a cutting tool to assist in the cutting operation (symbol, *CF*).

FUNCTIONS

1. The cutting fluid may assist the cutting operation in various ways, for example, extend the tool life, improve the finish, etc.

(*a*) It may, by reducing the accumulation of heat in the tool, extend the life of the tool for a given cutting speed or permit a higher cutting speed for the same tool life; or permit a greater feed resulting in greater metal removal in a given time;

(*b*) It may cool the tool and work and improve dimensional accuracy;

(*c*) It may assist in breaking up the chips so that they may be handled and removed from the machine with greater ease;

(*d*) It may reduce the power consumption and cutting forces; and ease the chips from the chip space, such as in tapping, drilling, and broaching;

(*e*) It may wash chips away from the work, fixture, and cutter.

TYPES AND DESIGNATIONS

2. There are several commonly used types of cutting fluids (symbol, *CF*) as follows:

(*a*) *Dry Cutting* (symbol, *D*) in which no liquid or solid is used, but either the natural flow or a blast of air, or some other gas, is applied to the tool point at normal or lower temperature, or some induced draft from the cutting area may assist in cooling the tool and work and carry away dust.

(*b*) *Aqueous Solutions* are water (*W*) or water solutions (*WS*). The latter contains salts, alkalis, or water soluble additives, but little or no oils or soaps.

(*c*) *Water Soluble Oils and Pastes:*

(*1*) *Water Emulsifiable "Soluble" Oils* (*W* Sol *O*) are prepared fluids designed to be mixed with water to form emulsions (*WEm*) to meet the requirements of each job.

(*2*) *Water Emulsifiable Pastes* (*W* Sol *P*) are prepared pastes designed to be mixed with water to form emulsions (*WEm*) to meet the requirements of each job.

(*d*) *Emulsions* (*WEm*) are mixtures of water and soluble oils or pastes in which the water carries combinations of oil, fats, wax, or chemicals in colloidal or finely dispersed suspension. Used as cutting fluids in general practice, the water content may range up to 100 parts to 1 by volume.

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[1] These proposed definitions are under the jurisdiction of the A.S.T.M. Committee D-2 on Petroleum Products and Lubricants. Published as information, June, 1949.

(*e*) *Straight Oils:*

(*1*) *Straight Mineral Oils* may consist of such oils as kerosine (*Ker*), or other low-viscosity petroleum fractions, such as mineral seal (*MS*), or higher-viscosity mineral oils (*MO*).

(*2*) *Straight Fixed* (Fatty Oils) (*FO*) consist of animal, fish, vegetable, or synthetic equivalents.

(*f*) *Mixed Oils* are a combination of straight mineral and straight fatty oils, such as mineral-lard (*MO L*) and mineral-fatty oils (*MO F*).

(*g*) *Cutting Oil Bases* (*BO*) are concentrates usually designed to be blended with mineral oils to meet specific requirements.

(*h*) *Chlorinated Mineral Oils* (*Cl MO*) are mineral oils containing effective chlorine compounds.

(*i*) *Sulfurized Mineral Oils* (*S MO*) are mineral oils containing effective sulfur compounds.

(*j*) *Sulfurized-Chlorinated Mineral Oils* (*S-Cl MO*) are mineral oils containing effective sulfur and chlorine compounds.

(*k*) Other elements or substances are also sometimes used in cutting fluids, such as graphite, mica, talc, phosphorous compounds, etc.

SUGGESTED SUMMARIZED KEY FOR CUTTING FLUIDS (*CF*)
(May be used for Tabular Data, Questionnaires, etc.)

Symbol	Term
D	Dry cutting.
W	Water.
WS	Water solutions of salts or alkalis.
WEm	Water solution of oil, soap, or wax.
WSol O	Water-soluble or emulsifiable oil.
WSol P	Water-soluble or emulsifiable paste.
MO	Straight mineral or petroleum oils.
Ker	Kerosine.
FO	Straight fixed or fatty oils, such as animal, fish, or vegetable.
LO	Lard Oil.
MO	Mixed Oils or Mineral-fatty oils such as fatty oils plus mineral oils, for example: *MO* + *FO*, 9–1; or *MO* + *LO*, 9–1.
BO	Base oils to be blended for use, for example: *BO* + *10* per cent of *MO* is *BO* + *MO*, 9–1.
S MO	Sulfurized mineral oil (170 sec. viscosity Sayblot Universal at 100 F.) as *S MO* (170 sec. viscosity)
S BO, 1–10 (140 sec. viscosity)	Sulfurized base oil blended with 10 parts low-viscosity mineral oil to give a final viscosity of 140 sec. Saybolt Universal at 100 F.
Cl MO	Chlorinated mineral oil.
S-Cl MO	Sulfurized-chlorinated mineral oil.
S-Cl MO, 1–5	Sulfurized-chlorinated mineral oil blended, for example, with 5 parts of low-viscosity mineral oil of 85 sec. viscosity.
S-Cl BO, 1–15 (160 sec. viscosity)	Sulfurized-chlorinated base oil blended with 15 parts of low-viscosity mineral oil to give 160 sec. viscosity at 100 F.
Gr MO	Graphitic mineral oil.
S BO	Sulfurized base oil (base).
S FO	Sulfurized fatty oil (base).
S BO MO, 1–10	Sulfurized base oil blended with 10 parts light mineral oil.

APPENDIX IV

PROPOSED CARBURETOR JACKET FOR USE WITH MOTOR AND RESEARCH METHODS TO RATE HIGH VAPOR PRESSURE FUELS

Published as Information Only

The Division on Combustion Characteristics, of A.S.T.M. Committee D-2 on Petroleum Products and Lubricants, has made available a carburetor jacket for rating high vapor pressure fuels with the *Motor* (D 357 – 48) and *Research* (D 908 – 48 T) Methods. With this equipment, high vapor pressure fuels can be chilled with dry ice to prevent the occurrence of vapor lock in the liquid flow of the fuel to the carburetor jets, as well as to minimize the loss of light fractions from the fuel. It is an additional piece of equipment which may be used only with the present standard adjustable-level three-bowl carburetor. When utilizing the carburetor jacket, the rating procedure is the same as presently specified with the exception that the jacket encloses the carburetor assembly and does not permit the use of the sight glass in obtaining the float level for maximum knock.

APPARATUS

The carburetor jacket for rating high vapor pressure fuels is available from the Waukesha Motor Company, Waukesha, Wisconsin, as Part No. GP 214-269. The jacket is designed for the use of dry ice *only*. Ratings are obtained in the normal manner except that the determination of the float-level setting for maximum knock must be obtained without the use of the sight glass, since it is completely enclosed by the jacket. In order to locate the carburetor float level for maximum knock when using the jacket, it is necessary to make successive settings of the adjusting screw until the knockmeter readings reach a peak and then fall off. Then the adjusting screw setting which will repeat the knockmeter peak reading must be found by trial and error.

NOTE.—The maximum knock float-level setting can be obtained in the conventional manner through use of the sight glass by removing the part marked 109463 D and installing a plexiglass door at the proper level. If frosting of the sight glass occurs a suitable defrosting agent can be applied to it. Alteration of the equipment in this manner also facilitates changing of jets and rearranging dry ice at the bottom of the jacket when necessary.

INSTALLATION

The carburetor jacket is shipped completely assembled by means of sheet metal screws and must be dismantled before installation on the engine carburetor. It is not necessary to remove the piece marked 109463 E from the part number 109463 D. Installation is made on the carburetor assembly nearest the panel board. Part numbers are stamped on the various pieces making up the assembly. The jacket is attached to the engine as follows:

(*1*) Remove the adjusting screw knob, support post cap and drain cock from the carburetor assembly nearest the panel board (bowl No. 1).

(*2*) Install the drilled and tapped support post cap that is provided.

(*3*) Place the smallest piece of the assembly, marked 109463 B, against the rear of the carburetor body such that the solid section of the piece faces the back and the cut-out section of the top fits into the carburetor body below the venturi section.

(*4*) Place the large section, marked 109463, around the carburetor bowl so that the cut-out portion will rest on the tank bracket.

(*5*) Adjust the jacket so that the hole for the drain cock will line up and replace the drain cock. Fasten the bracket welded to the back of the large section to the new support post cap with the provided screw. This locates the jacket.

(*6*) Place the remaining section, marked 109463 A, over the front of the carburetor body so that the drilled holes line up with the holes in the sections previously put into position.

(*7*) Tighten the three sections together with sheet metal screws.

(*8*) Attach the extension for the adjusting screw knob to the adjusting screw, by means of the Allen set screw provided. Attach the adjusting screw knob to the lower end of the extension for the adjusting screw by means of the other Allen set screw provided.

(*9*) Attach the front cover, 109463 D, to the jacket.

(*10*) Place the cover marked 109463 C on the top. No screws are provided.

(*11*) If it is necessary to change a jet or rearrange the dry ice at the bottom of the jacket the small rectangular piece, marked 109463 E, can be detached from the lower half of the front cover, 109463 D.

PREPARATION FOR RATING SAMPLES

Using dry ice only, place several small pieces in the jacket around the carburetor body. Additional dry ice, approximately $2\frac{1}{2}$ in. in length and width and 1 in. in thickness is added in accordance with requirements dictated by the vapor pressure of the sample being tested. With a fuel having a very high vapor pressure it may be necessary to fill the jacket until level with the top of the bowl. Care should be taken to prevent packing of the ice, especially in the rear of the adjusting screw because this will prevent movement of the adjusting screw when obtaining the float level for maximum knock.

CHANGES IN MOTOR AND RESEARCH METHODS

For rating fuels having high vapor pressures the procedure is the same as presently specified for the Motor (D 357 – 48) and Research (D 908 – 48 T) Methods, except for the following changes:

Method D357 – 48, Sections 6 (o) and 12 (b) and Method D 908 – 48 T, Sections 6 (n) and 12 (b).—Add the following sentence: "When using the jacketed carburetor to rate fuels having high vapor pressures, obtain the float level for maximum knock without the aid of the sight glass."

Supplement I on Apparatus, Section 112 (a).—Insert the following after the first sentence: "For rating fuels having high vapor pressures a jacket for dry ice may enclose the carburetor nearest the panel board."

APPENDIX V

PROPOSED METHOD FOR DETERMINATION OF COLOR INDEX OF PETROLEUM PRODUCTS BY PHOTOELECTRIC COLORIMETER[1]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pa.

Scope

1. This method describes a procedure for the photoelectric determination of a color index of petroleum products. It is designed particularly as a method for determining compliance with specification requirements for color characteristics of lubricating oils and products having similar spectral properties. It is not applicable to samples that show turbidity at room temperature or to materials whose spectral properties differ markedly from sample to sample.

NOTE 1.—The color index gives a reasonably satisfactory correlation with results obtained by present A.S.T.M. visual methods applied to petroleum products. Figure 1 may be used to convert color index values to corresponding A.S.T.M. Union color numbers (A.S.T.M. Method D 155, Test for Color of Lubricating Oil and Petrolatum by Means of A.S.T.M. Union Colorimeter)[2] with an uncertainty of approximately one half of an A.S.T.M. color number in most cases. The color index values for materials differing markedly in spectral properties from normal petroleum products are not correlatable with visual measurements but they are reproducible and, for that reason, have utility.

Definitions

2. (*a*) *Daylight Transmittance.*—The corrected instrument response for a 20-mm. layer of sample, expressed in percentage transmittance, relative to that for distilled water and found by use of the tristimulus green filter specified in Section A3 of the Supplement.

(*b*) *Blue Transmittance.*—The corrected instrument response for a 20-mm. layer of sample, expressed in percentage transmittance, relative to that for distilled water and found by use of the tristimulus blue filter specified in Section A3 of the Supplement.

(*c*) *Color Index.*—Color index is the numerical value of the daylight transmittance for values from 3.0 to 95.0 per cent, inclusive. For daylight transmittance values above 95.0 per cent, color index is equal to ninety plus one tenth of the blue transmittance. For daylight transmittance values below 3.0, the color index is a value calculated from the daylight transmittance of a solution of one part by weight of sample in nine parts of colorless *n*-heptane, as specified in Section 8 (*d*).

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[1] This proposed method is under the jurisdiction of the A.S.T.M. Committee D-2 on Petroleum Products and Lubricants. Published as information, June, 1947; Revised, June, 1949.

This method is a revision of the Proposed Method for Determination of Color Index of Petroleum Products by Photoelectric Colorimeter, published as information in Appendix IV to the 1947 Report of A.S.T.M. Committee D-2, *Proceedings*, Am. Soc. Testing Mats., Vol. 47, p. 307 (1947). It differs mainly: (*1*) in the substitution of the ICI tristimulus green and blue filters for the north sky and violet filters, respectively, and (*2*) in the elimination of the red transmittance measurement and its use for classification of the sample as being normal or abnormal in color. The historical and technical development of the photoelectric color index method is discussed in the article "Photoelectric Measurement of a Color Index of Liquid Petroleum Products" by L. Lykken, ASTM BULLETIN, No. 154, October, 1948, p. 68 (TP 226).

[2] 1949 Book of A.S.T.M. Standards, Part 5.

Outline of Method

3. By means of a specified photoelectric colorimeter, the daylight and blue transmittances of a series of glass color standards (resembling light to dark petroleum oils) are measured relative to a clear glass reference standard. Calibration graphs are prepared for the green and blue filters (of specified spectral properties) by plotting, for each filter, the deviations between certified and observed transmittances of each glass color standard. The daylight transmittance of the sample relative to distilled water is measured and the observed value is corrected by means of the appropriate calibration graph. The daylight transmittance is reported as the color index of the sample for values from 3.0 to 95.0 per cent. For daylight transmittances greater than 95.0 per cent, the measurement is repeated, using the blue filter, and the color index is calculated empirically. For daylight transmittances less than 3.0 per cent, the measurement is repeated with the green filter, using a 10 per cent solution of the sample in *n*-heptane, and the color index is obtained from an empirically derived table.

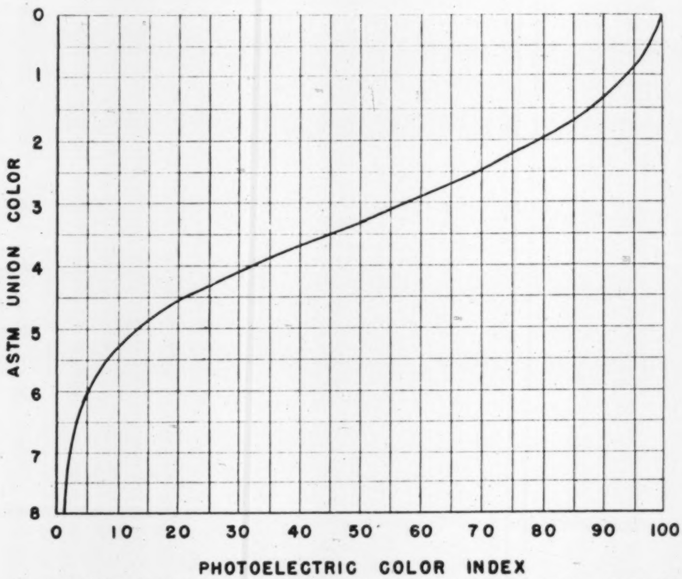

FIG. 1.—Correlation of Photoelectric Color Index with A.S.T.M. Union Color Number.

NOTE.—Conversion from photoelectric color index is generally accurate within one half of an A.S.T.M. Union Color number.

Apparatus

4. *Photoelectric Colorimeter, Sample Cells, Color Filters, and Glass Color Standards* as specified in the Supplement.

Diluent

5. *n-Heptane*, essentially pure having a color index of 99.5 or higher.

Standardization of Apparatus

6. (*a*) Using the green and blue filters, measure the transmittance of the glass color standards listed in Table I relative to the clear glass reference standard; use the procedure given in Section 7 and place the standards in the cell compartment adjacent to the photocell. Obtain the difference between these observed values and the certified values furnished

by the National Bureau of Standards, the certified values to be obtained in accordance with the definitions given in Section A4 of the Supplement. Consider the apparatus unsuitable for use if the observed transmittances differ from the certified transmittances by more than the permissible variations shown in Table I (Note 2). Repeat the standardization at monthly intervals, or more often if necessary, to guard against appreciable changes in instrument response.

TABLE I.—COLORIMETER RESPONSE REQUIREMENTS.

Standard	Permissible Variations from N.B.S. Certified Percentage Transmittance Values	
	Green Filter	Blue Filter
N.B.S. No. 12........	±3	±5
N.B.S. No. 13........	±3	±5
N.B.S. No. 14........	±5	±2
N.B.S. No. 15........	±5	...
N.B.S. No. 16........	±2	...
N.B.S. No. 21........	±5	±1
N.B.S. No. 22........	±5	±2
Lampblack...........	±0.5	±0.5

NOTE 2.—An instrument can in some cases be adjusted to meet the requirements of this section by appropriate manipulation of the lamp rheostat or light reduction devices, or both.

(*b*) Considering standards Nos. 12 through 16 only, subtract the observed transmittances obtained relative to the clear glass standard with the green filter from the corresponding certified value for the color standard furnished by the National Bureau of Standards. Assign to the difference thus obtained the appropriate algebraic sign; thus, if the observed relative transmittance is smaller than the certified value, assign a positive sign to the difference, and, if the observed transmittance is greater than the certified value, assign a negative sign to the difference. Prepare a correction graph (Note 3) for the green filter by plotting the differences against the observed values and connecting each plotted point to its neighbor with a straight line; draw the graph through zero difference at 100 per cent transmittance and through the difference between zero and the observed value for lampblack at zero transmittance. Use the values taken off this graph, with their algebraic signs, as corrections to be applied to observed transmittance readings. Prepare a similar graph for the blue filter.

NOTE 3.—If all the transmittance differences for either filter obtained in accordance with Paragraph (*b*) are less than 0.5 unit, the appropriate correction graph need not be prepared.

Procedure

7. (*a*) Adjust the colorimeter in accordance with the manufacturer's operating instructions so that a galvanometer deflection of 10 to 50-mm. scale divisions will result upon changing the slide wire dial from 100 to 90 per cent transmittance, using the green filter and having the instrument balanced at 100 per cent transmittance for distilled water in the sample cell.

(*b*) Adjust the temperature of the sample to 25 ± 5 C. (Note 4). Fill one of the pair of matched 20-mm. sample cells (Note 5) with distilled water and the other with sample; allow any entrained air bubbles to escape. Polish the outside surfaces of the cells with a clean, lint-free cloth or tissue, and place the water-filled cell in the colorimeter adjacent to the photocell. Wipe the green filter with a clean lint-free cloth or tissue, put the filter in position in the colorimeter, and adjust the colorimeter to read 100 per cent transmittance. Replace the water cell with the cell containing the sample and measure the transmittance of the sample (Note 6), estimating to the nearest 0.1 per cent. Reinsert the water cell and check the instrument adjustment. If this reading differs from 100 per cent by more than

0.5 per cent, readjust the colorimeter and obtain a new reading for the sample.

NOTE 4.—With proper precautions, satisfactory results may sometimes be obtained with samples that require heating to eliminate a cloud or to melt the sample. In such cases, the sample should not be heated over 5 C. above the cloud point or 15 C. above the melting point. In any event, the method should not be used for samples that must be heated above 40 C.

NOTE 5.—Clean the sample cells before use by immersion in chromic acid cleaning solution. Rinse thoroughly, first with distilled water and then with acetone, and dry with a stream of clean air. If a series of samples is being analyzed, it suffices to rinse out the cell with a hydrocarbon solvent and then with acetone and dry.

NOTE 6.—The light passing through the sample may cause a change in color of unstable products. With such samples, the measurements should be made as rapidly as possible to minimize this effect and the degree of this instability should be stated in the report.

(*c*) If the daylight transmittance is above 95.0 per cent, obtain the blue transmittance for the sample, using the blue filter and adjusting the instrument to a galvanometer deflection of 10 to 50-mm. scale divisions per 10 per cent transmittance units as directed in Paragraph (*a*), but use the blue filter in place of the green filter; otherwise proceed as directed in Paragraph (*b*).

(*d*) If the daylight transmittance is below 3.0 per cent, prepare a solution consisting of one part by weight of sample to nine parts by weight of *n*-heptane and obtain the daylight transmittance as directed in Paragraph (*b*).

(*e*) Make *all* transmittance measurements with the *same* light intensity and color temperature (that is, the same applied voltage, lamp rheostat setting, light reduction device, etc.) as used in the standardization of the apparatus (Section 6).

Calculation and Report

8. (*a*) Determine the correction for the observed reading, obtained as directed in Section 7, from the appropriate correction graph prepared as directed in Section 6 (*b*). Apply this correction to the observed reading and obtain the daylight or blue transmittance.

TABLE II.—DETERMINATION OF COLOR INDEX[a] FROM DAYLIGHT TRANSMITTANCE OF HEPTANE SOLUTION OF THE SAMPLE.

H[b]	0	1	2	3	4	5	6	7	8	9
0	0.00	0.003	0.005	0.008	0.010	0.013	0.015	0.018	0.020	0.023
10	0.025	0.028	0.030	0.033	0.035	0.038	0.040	0.043	0.045	0.048
20	0.050	0.053	0.055	0.058	0.060	0.063	0.065	0.068	0.070	0.073
30	0.075	0.078	0.080	0.083	0.085	0.088	0.090	0.093	0.095	0.098
40	0.10	0.12	0.15	0.18	0.21	0.25	0.30	0.35	0.41	0.47
50	0.55	0.64	0.74	0.86	0.98	1.1	1.3	1.5	1.7	1.9
60	2.2	2.5	2.8	3.1	3.5	4.0	...	...	...	...

[a] For heptane solutions having daylight transmittances below 40, the color index is taken as $0.0025H$; above 40 the color index is based on the expression.

$$\text{Color index} = \text{antilog}\,[2 - 7.5(2 - \log H)]$$

[b] The symbol H = daylight transmittance of the *n*-heptane solution of the sample, in per cent.

(*b*) If the daylight transmittance of the sample is between 3.0 and 95.0 per cent inclusive, report that number to the closest 0.1 unit as the color index.

(*c*) If the daylight transmittance of the sample is 95.1 per cent or greater, calculate the color index from the blue transmittance as follows:

$$\text{Color index} = 90 + 0.1\,B$$

where:

B = blue transmittance in per cent.

Report the number so obtained to the nearest 0.1 unit as the color index.

(*d*) If the daylight transmittance of a 20-mm. layer of the sample is less than 3.0, determine the color index from Table

II using the daylight transmittance of the *n*-heptane solution of the sample. Report the nearest number given in Table II as the color index.

Precision

9. The results should not differ from the mean by more than the following amounts:

Color Index	**Repeatability,** One Operator and Apparatus	**Reproducibility,** Different Operators and Apparatus
0.0 to 2.9	0.2	0.4
3.0 to 95.0	1.0	2.0
95.1 to 100	0.5	1.0

NOTE 7.—Results on samples that are markedly "off color" cannot in general be expected to show the above precision.

SUPPLEMENT

APPARATUS

Photoelectric Colorimeter:

A1. The photoelectric colorimeter[3] shall conform to the response requirements prescribed in Section 6 and shall be made up of the following components:

(*a*) *Light Source.*—The light source shall conform to the following requirements:

(*1*) The light source shall be an incandescent tungsten lamp designed to operate at a color temperature of approximately 3000 K. The lamp base shall be so constructed that the lamp may be reproducibly positioned and may be centered with respect to the optical elements of the colorimeter.

(*2*) The colorimeter shall be equipped with a constant voltage source whose output is constant to ± 1 per cent.

(*3*) The light source circuit shall contain a rheostat or other device to permit adjustment of the color temperature of the lamp from approximately 2000 to 3000 K.

(*4*) The colorimeter shall be provided with suitable means to dissipate the heat generated by the light source; upon continuous operation for 1 hr. the temperature of the sample cell compartment shall not be more than 5 C. above room temperature.

(*b*) *Optical System.*—The optical system shall conform to the following requirements:

(*1*) The light from the lamp shall be passed through an optical system that will cause it to be incident substantially at right angles to the surface of the petroleum product.

(*2*) The filter holder shall reproducibly position the specified color filters.

(*3*) Means shall be provided for variably reducing the amount of light reaching both photocells without altering the spectral characteristics of the light. (Suitable means may consist of a series of reduction plates having holes of various diameters or metal screens having various ratios of opaque to transparent areas.)

(*4*) The sample cell and glass calibration standards described in Sections A2 and A4, respectively, shall be supported in such a manner that they are reproducibly positioned upon random insertion.

(*5*) The measuring and balance photocells shall be matched and of such type and response that the instrument will meet the requirements of Section 6. The adjustment of the colorimeter to read 100 per cent transmittance with distilled water in the sample cell shall be made by irradiation of the balance photocell.

(*c*) *Photoelectric Circuit.*—The photoelectric system may contain the following elements connected in a current bridge circuit:

(*1*) Measuring and balance photocells.

(*2*) A slide wire resistance equipped with a control dial graduated from 0 to 100 in units of 0.5 per cent transmittance, having linear response over the entire range.

(*3*) A galvanometer, having a coil resistance of 100 ± 20 ohms and a sensitivity of 0.06 ± 0.02 microamperes per millimeter scale division, used as a null indicator (the photoelectric circuit being adjusted until the galvanometer shows a deflection of zero scale divisions).

(*4*) A key switch that connects the galvanometer to the photoelectric circuit when held closed.

The Lumetron Model 402E Photoelectric Colorimeter, manufactured by the Photovolt Corp., 95 Madison Ave., New York 16, N. Y., has been found to be satisfactory for this purpose.

Sample Cells:

A2. Glass sample cells[4] shall have parallel planar sides and shall be of proper dimensions to permit use in the colorimeter employed. The length of the light path through the interior of the cell shall be 20.0 ± 0.1 mm.

Color Filters:

A3. The light filters[5] shall be made of essentially plane glass, or combinations of glass, in which the coloring material is uniformly dispersed. The filters shall retain their color indefinitely. They shall be of a suitable size and shape to permit use in the colorimeter employed. Two filters designated as green and blue shall be provided. These filters, in combination with the photoelectric colorimeter, shall yield observed transmittances of the glass color standards that agree with the certified transmittances within the tolerances prescribed in Section 6. The spectral transmittances, T_g and T_b, of such filters required to produce exact agreement may be calculated from the relative spectral sensitivity, S, of the photocell, and the relative spectral irradiance, E, of the light source as follows:

$$T_g = \frac{K_g \bar{y} E_c}{SE}$$

$$T_b = \frac{K_b \bar{z} E_c}{SE}$$

where:

$\bar{y}$ and $\bar{z}$ = two of the tristimulus values of the equal-energy spectrum (Table III, A.S.T.M. Method D 307, Test for Spectral Characteristics and Color of Objects and Materials),[6]

E_c = relative spectral irradiance of standard illuminant, c (representative of average daylight, Table I, Method D 307), and

K_g and K_b = constants of any desired value independent of wavelength. The actual green and blue filters must have spectral transmittances of approximately this character.

Glass Color Standards:

A4. The standards shall consist of eight essentially plane, 2-in. square, glasses or combinations of glasses. Five of the standards duplicate spectral characteristics of typical petroleum products, two of the standards (red and green) serve as additional checks on the apparatus (Section 6), and one is a clear glass. These standards shall be obtained from the National Bureau of Standards with certified daylight $(T/T_o)_d$ and blue $(T/T_o)_b$ transmittances relative to the clear glass reference standard defined as follows:

$$(T/T_o)_d = \sum_0^\infty \bar{y}E_c(T/T_o)\Delta\lambda \Big/ \sum_0^\infty \bar{y}E_c\Delta\lambda$$

$$(T/T_o)_b = \sum_0^\infty \bar{z}E_c(T/T_o)\Delta\lambda \Big/ \sum_0^\infty \bar{z}E_c\Delta\lambda$$

where the symbols have the same meanings as in Paragraph A3.

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[4] Suitable cells, if not supplied with the colorimeter, may be obtained from the Klett Manufacturing Co., 177 E. 87th St., New York, N. Y.; from Fischer and Porter Co., 3507 Country Lane Road, Hatboro, Pa.; or from Photovolt Corp., 95 Madison Ave., New York 16, N. Y.

[5] The tristimulus green and blue filters supplied by the Photovolt Corp., 95 Madison Avenue, New York 16, N. Y., are satisfactory.

[6] 1949 Book of A.S.T.M. Standards, Part 4.

APPENDIX VI

PROPOSED METHOD OF TEST FOR SULFUR IN PETROLEUM PRODUCTS BY THE CO_2-O_2 LAMP METHOD[1,2]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Scope

1. This method describes procedures for the determination of total sulfur in concentrations above 0.002 per cent by weight in liquid petroleum products. It is intended particularly for application to multiple analysis of two or more samples at the same time. The direct burning procedure (Section 6) is applicable to such materials as gasoline, kerosine, naphtha, and other liquids that can be burned completely and without smoking in a wick lamp. The blending procedure (Section 7) is applicable to aromatics, gas oils and distillate fuel oils, naphthenic acids, alkyl phenols, high sulfur content petroleum products, and many other materials that can not be burned satisfactorily by the direct burning procedure. Neither procedure is suitable for accurate analysis of samples that contain appreciable concentrations of halogens, phosphorus, nitrogen, or other acid-forming elements.

NOTE 1.—Results obtained by this method are expected to be identical with those obtained by A.S.T.M. Method D 90 - 47 T, Test for Sulfur in Petroleum Products by the Lamp - Gravimetric Method,[3] within the limits of precision and accuracy of the two methods. This method is appreciably more rapid than the lamp - gravimetric method when applied to routine multiple operations, and is generally to be preferred for such applications.

Outline of Method

2. The sample is burned in a closed system, using a wick-type lamp and an artificial atmosphere composed of 70 per cent carbon dioxide and 30 per cent oxygen to prevent formation of nitrogen oxides. The oxides of sulfur are absorbed and oxidized to sulfuric acid by means of hydrogen peroxide and, after flushing with air to remove dissolved carbon dioxide, the absorbent is titrated with sodium hydroxide solution.

Apparatus

3. The apparatus shall consist of the following:

(*a*) *Lamps, Chimneys, Absorbers, and Spray Traps* (Fig. 1) as specified in the Supplement

(*b*) *Cotton Wicking.*—Clean, unused, uniform, two-strand twisted cotton wicking of good quality, weighing 5 to 6 mg. per cm. per strand.

(*c*) *Manifold System* consisting of a vacuum manifold with regulating device, values, etc., and a dual manifold (burner and chimney) supplying a gas mixture of approximately 70 per cent CO_2 and 30 per cent O_2 at regulated pressures.

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[1] This proposed method is under the jurisdiction of the A.S.T M Committee D-2 on Petroleum Products and Lubricants.

[2] Published as information, October, 1947; and with addition of Supplement B in June, 1949

[3] 1949 Book of A.S.T.M. Standards, Part 5.

The vacuum manifold shall be connected to a pump of sufficient capacity to permit a steady gas flow about 3 liters per min. through each absorber, and to maintain a constant manifold pressure of approximately 40 cm. of water below atmospheric. The gas mixture in the burner manifold shall be maintained at a nearly constant pressure of 1 to 2 cm. of water. A suitable arrangement is described in the Supplement, but any other similar system may be used.

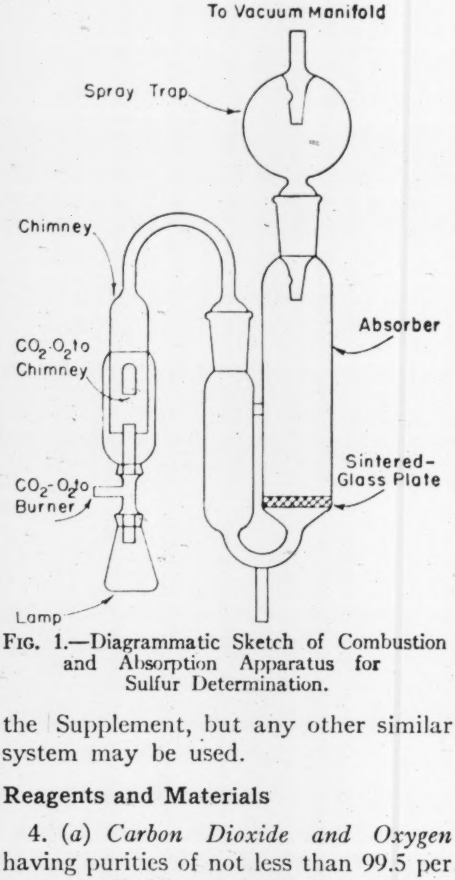

FIG. 1.—Diagrammatic Sketch of Combustion and Absorption Apparatus for Sulfur Determination.

Reagents and Materials

4. (*a*) *Carbon Dioxide and Oxygen* having purities of not less than 99.5 per cent, supplied in metal cylinders. These gases shall show no detectable sulfur by blank determination.

(*b*) *Diluent.*—The diluent used shall have a sulfur content less than 0.001 per cent, be completely miscible with the sample to be analyzed, and permit burning at a moderate rate without smoking. Normal heptane, *iso*octane, and absolute ethyl alcohol have been found suitable.

(*c*) *Hydrogen Peroxide* (*3 per cent*).—Dilute c.p. H_2O_2 (30 per cent) with distilled water. Store in a dark-colored glass-stoppered bottle.

(*d*) *Methyl Red Indicator Solution* (*0.1 per cent*).—Dissolve 0.1 g. of methyl red in 6 ml. of 0.05 *N* NaOH and dilute to 100 ml. with distilled water. Remove any undissolved solids by filtration.

(*e*) *Standard Sodium Hydroxide Solution* (*0.05 N*).—Dilute 2.8 ml. of saturated NaOH solution to 1 liter, using for this purpose the clear saturated solution decanted after standing long enough to permit any precipitate to settle out. Standardize by titration against standard acids in the absorber in the manner described in Section 8. Store in a chemically resistant glass bottle and protect to minimize contamination from CO_2 in the air.

NOTE 2.—The calculation of results may be simplified by adjusting the normality of the NaOH solution to 0.0624 ± 0.0001. One milliliter of the NaOH solution then will be equivalent to 0.0010 g. of sulfur.

Preparation of Apparatus

5. (*a*) When the apparatus is first assembled, adjust the individual valves between the vacuum manifold and the spray traps so that approximately 3 liters of air per minute will be drawn through each absorber when the chimney outlets are open to the atmosphere, the absorber is charged with 30 ± 2 ml. of water, and the pressure in the vacuum manifold is maintained at approximately 40 cm. of water below atmospheric. When all adjustments have been made, remove the water from the absorbers.

(*b*) Neutralize the H_2O_2 (3 per cent) immediately before use. As 30 ml. of the solution are needed, transfer to a beaker multiples of 30 ml. sufficient for the number of absorbers to be used simultaneously. Add one drop of methyl red indicator for each 100 ml. and add 0.05 *N* NaOH dropwise until the color changes from pink to yellow.

(*c*) Introduce 30 ± 2 ml. of the freshly neutralized H_2O_2 (3 per cent) into the larger bulb of each absorber. Attach the spray traps and chimneys and connect them to their respective manifolds by means of rubber tubing. Close the chimney openings by means of corks.

(*d*) With the burner control valves closed, the valve to the vacuum regulator fully open, and the pressure in the vacuum manifold adjusted to approximately 40 cm. of water below atmospheric, turn on the CO_2 and O_2. Adjust the chimney manifold control valve so that, at the required flow through the absorbers, only a small stream of gas escapes at the pressure regulator, a small stream of air enters at the vacuum regulator, and the pressure in the chimney manifold is 1 to 2 cm. of water. Minor adjustment of the vacuum regulator and vacuum control valve may be necessary to achieve this condition.

NOTE 3.—It is convenient to balance the gas flow system by regulating the pressure in the vacuum manifold. This is done by raising or lowering the air inlet tube in the vacuum regulator by sliding it in a rubber sleeve.

(*e*) Thread the required number of burners with four 15-cm. lengths of cotton wicking by doubling two 30-cm. lengths, inserting the looped ends into the top of the inner tube of the burner, and drawing the wicking through by means of a metal hook. Trim the wick as close as possible to the top of the burner with a pair of sharp scissors; then draw the wick down until the trimmed edge is flush with the top of the burner (see Note 5). It is essential that thoroughly cleaned burners and new wicking be used for each test.

Procedure for Direct Combustion

6. (*a*) By means of a pipet, introduce into the flask of each burner an approximate quantity of sample as indicated in Table I. Stopper the flasks with clean, numbered corks. Weigh each flask and its burner to 0.005 g.

NOTE 4.—While the stoppered flasks and prepared burners may all be weighed separately, it is usually more convenient to place each flask and its burner on the balance pan and obtain the combined weight in a single weighing.

(*b*) Handling each lamp individually, insert the burner in the flask. As soon as the sample has risen by capillary action to the top of the wick, connect the side tube of the burner to the burner manifold by means of rubber tubing. Light the burner with a sulfur-free flame (such as an alcohol lamp) and insert into the chimney, pinching off the connection between the chimney and the chimney manifold during the insertion if the flame tends to be blown out. At the same time, adjust the gas flow to the burner so that the flame is maintained at a point just below smoking and has a steady, symmetrical appearance. Continue in this manner until all lamps have been placed in the chimneys. Make any minor adjustment of the chimney control valve necessary to maintain the required pressure (see Section 5(*d*)). During the burning, and particularly during the latter stages when the flame becomes small, decrease the gas supply to the burners in order to prevent extinction of the flames.

TABLE I.

SULFUR CONTENT, per cent by weight	SAMPLE SIZE	
	g.	ml.
Under 0.05	10 to 15	20
0.05 to 0.3	5 to 10	10
0.3 to 1	3 to 5	5
Over 1	2 to 3	3

NOTE 5.—Most types of samples burn with a luminous yellow flame, the size and shape of which is dependent upon the gas flow to the burner, the volatility of the material, the tightness of the fit of the wick in the burner tube, and the position of the top of the wick relative to the top of the burner. It is preferable that the latter two variables be fixed with relation to the first before burning is started so that the flame can be controlled by variation in rate of gas flow. Highly volatile samples require a tight-fitting wick, the top of which may need to be several millimeters below the top of the burner, and in extreme cases may have to be cooled in ice during the burning. Less volatile materials require a more loosely fitting wick and require warming. In any case, it is essential that the flame burn smoothly and symmetrically and without jets in the inner cone or smoke on the outer fringes. Satisfactory combustion of materials difficult to burn can sometimes be obtained by increasing the O_2 content of the combustion atmosphere, but never above 40 per cent. Materials that can not be burned properly under those conditions shall be burned by blending as described in Section 7.

(*c*) When the burning of each sample is completed (as evidenced by the flame becoming small owing to depletion of the sample), remove the lamp from the chimney, extinguish the flame, shut off the CO_2 - O_2 supply to the burner and stopper the chimney opening. Immediately reweigh the lamp, burner, and numbered cork. When all combustions have been completed, turn off the CO_2 and O_2 supplies and close the connection to the vacuum regulator; this will cause air to be drawn into the chimney manifold through the manometer. Allow air to be drawn through the absorbers in this manner for 5 min. to remove dissolved CO_2 from the absorbent; then close the vacuum control valve.

NOTE 6.—If it is desired to conserve the combustion atmosphere, the gas flow through each individual absorber may be turned off upon completion of the burning period. To accomplish this, pinch off the rubber tubing connecting the spray trap to the vacuum manifold, reduce the flow of mixed gases at the rotameters proportionately, and readjust the vacuum control valve and the chimney control valve. When the burning of all samples has been completed, it is necessary to remove the pinch clamps and readjust the vacuum control valve in order to draw air at the required rate through the absorbers for removal of dissolved CO_2.

(*d*) Rinse the chimneys and spray traps with 30 to 40 ml. of distilled water, adding the rinsings to the absorbers, and proceed as directed in Section 8.

(*e*) *Blank.*—Leave the chimney of the blank absorber (Section 5(*c*)) stoppered, and allow the CO_2 - O_2 stream to pass through that absorber until all samples started at one time have finished burning. Titrate the absorber liquid as described below. Normally the combustion gas blank will be negligible, but if the blank titration is more than 0.1 ml. discard the determination and replace the CO_2 cylinder.

TABLE II.

Sulfur Content, per cent by weight	Sample Size	
	g.	ml.
0.5 and under	3 to 4	5
Over 0.5	2 to 3	3

Procedure for Blending and Combustion

7. (*a*) Add 6 ml. of sulfur-free diluent to each flask. Stopper the flasks with numbered corks and weigh to 0.005 g. By means of a pipet, introduce into the flask of each burner an approximate quantity of sample as indicated in Table II; swirl to mix thoroughly and reweigh (see Note 4).

NOTE 7.—Alternatively, make a quantitative 40 per cent blend of the sample in sulfur-free diluent and proceed as described in Section 6.

(*b*) Insert the burner and burn as described in Section 6 (*b*). Remove each lamp from its chimney as the flame nears extinction and extinguish the flame. Add 2 ml. of diluent, allowing the diluent to rinse down the walls of the flask

Burn the additional diluent, and repeat the addition of diluent and burning one more time so that a total of 10 ml. of diluent has been burned.

(*c*) After all lamps have completed burning, turn off the CO_2 and O_2 supplies, close the connection to the vacuum regulator, draw air through the absorbers for 5 min., and finally close the vacuum control valve. Rinse the chimneys and spray traps with 30 to 40 ml. of distilled water, adding the rinsings to the absorbers, and proceed as directed in Section 8.

Analysis of Absorbent

8. Add 3 to 4 drops of methyl red indicator solution to the liquid in each absorber. Titrate the absorbent by introducing 0.05 *N* NaOH solution from a buret into the smaller bulb of the absorber. Use a 10 ml. microburet if less than 10 mg. of sulfur is expected to be present in the absorber. Stir during the titration by applying suction intermittently with the mouth to the top of the larger bulb (preferably by means of a short length of rubber tubing fitted to a perforated rubber stopper of appropriate size).

NOTE 8.—When incomplete combustion of the sample occurs, the absorber liquid will foam excessively. Also, during the titration, the air drawn through the absorber will have a characteristic taste or odor and the end point will be broad. In such cases, discard the determination.

Calculation

9. Calculate the sulfur content of the sample as follows:

$$\text{Sulfur, per cent by weight} = \frac{AN \times 1.603}{W}$$

or, if the normality of the NaOH solution has been adjusted to 0.0624 ± 0.0001:

$$\text{Sulfur, per cent by weight} = \frac{A}{W \times 10}$$

where:

A = milliliters of NaOH solution used in titrating the acid in the sample absorbent,

N = normality of the NaOH solution, and

W = grams of sample used.

NOTE 9.—When blends are used as described in Note 7, modify the calculations by using the measured aliquot portion of a sample, *W*.

Precision and Accuracy

10. (*a*) Results should not differ from the mean by more than the following amounts:

Sulfur Content, per cent by weight	Repeatability, One Operator and Apparatus	Reproducibility, Different Operators and Apparatus
0.002 to 0.25......	0.001	0.002
Over 0.25.........	0.5 per cent of mean	1 per cent of mean

(*b*) Results should not differ from the true value by more than the following amounts:

Sulfur Content, per cent by weight	Accuracy
0.002 to 0.25..........	0.002
Over 0.25............	1 per cent of true value

SUPPLEMENT A

APPARATUS

Apparatus:

A1. The apparatus shall consist of the following:

(*a*) *Lamp.*—A lamp of chemically resistant glass, consisting of a 25-ml. Erlenmeyer flask and a burner that conforms to the dimensions shown in Fig. 2. The burner consists of two concentric glass tubes, the external tube having an arm, provided with standard-taper glass joints for connection with the flask and the chimney. The upper ends of both burner tubes shall be polished and shall have plane surfaces that are in the same horizontal plane. The burner shall have a 1-mm. opening near its

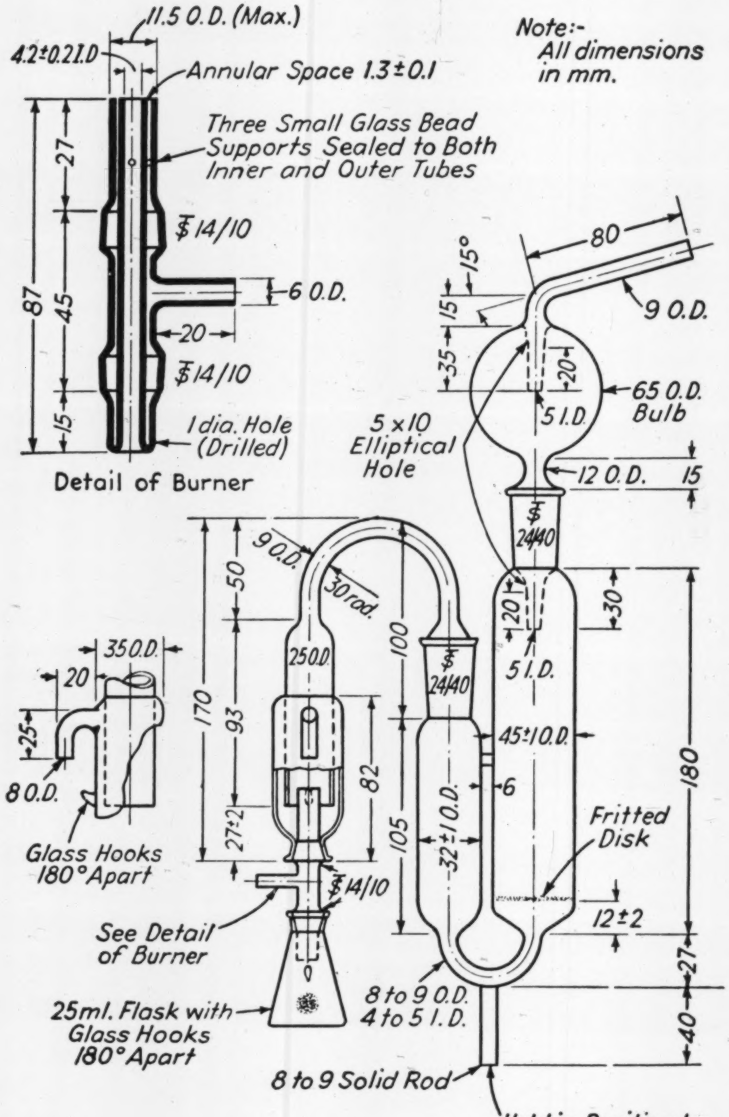
11.5 O.D. (Max.)
4.2±0.2 I.D.
Annular Space 1.3±0.1
Note:-
All dimensions in mm.
Three Small Glass Bead Supports Sealed to Both Inner and Outer Tubes
27
87
45
15
$ 14/10
6 O.D.
20
$ 14/10
1 dia. Hole (Drilled)
Detail of Burner
80
15°
15
9 O.D.
35
20
65 O.D. Bulb
5 I.D.
5 x 10 Elliptical Hole
12 O.D.
15
$ 24/40
9 O.D.
30 rad.
50
100
170
93
27±2
25 O.D.
82
35 O.D.
20
25
8 O.D.
Glass Hooks 180° Apart
$ 24/40
30
20
5 I.D.
180
45±1 O.D.
6
105
32±1 O.D.
Fritted Disk
12±2
27
40
$ 14/10
See Detail of Burner
25 ml. Flask with Glass Hooks 180° Apart
8 to 9 O.D.
4 to 5 I.D.
8 to 9 Solid Rod
Held in Position by Any Suitable Support

FIG. 2.—Detailed Drawing of Combustion and Absorption Apparatus for Sulfur Determination.

NOTE.—In the case of those dimensions for which no specific tolerances are designated above, the permissible variation is plus or minus 10 per cent to the nearest millimeter, provided, however, that in no case shall the deviation be greater than 5 mm.

base to allow equalization of pressure between the chimney and the flask. When connected with the chimney, the lamp shall be held in position by rubber bands or metal springs stretched between glass hooks on the flask and chimney.

(*b*) *Chimney.*—A chimney of chemically resistant glass conforming to the dimensions shown in Fig. 2, provided with standard-taper glass joints for connection with the burner and absorber.

(*c*) *Absorber.*—An absorber of chemically resistant glass conforming to the dimensions shown in Fig. 2, provided with standard-taper glass joints for connection with the chimney and spray trap. A fritted disk with average pore diameter from 150 to 200 microns shall be sealed in the larger of two bulbs of the absorber. The fritted disk should be of such a porosity that, when 50 ml. of water is placed in the absorber and air is passed through at the rate of 3.0 liters per minute in the forward direction, the pressure differential between the two sides of the absorber is between 15 and 23 cm. of water and the air is dispersed uniformly.

(*d*) *Spray Trap.*—A spray trap of chemically resistant glass conforming to the dimensions shown in Fig. 2, provided with a standard-taper glass joint for connection with the absorber.

(*e*) *Manifold System.*—A satisfactory vacuum and combustion atmosphere manifold and supply system for supplying the required CO_2 - O_2 mixture to the lamp assemblies is shown diagrammatically in Fig. 3. The gases are supplied from commercial cylinders, the pressure of each gas being adjusted to 10±2 psi. by means of two single-stage regulating valves to ensure constant pressure at the flow regulating needle valves. It is necessary to pass the CO_2 through a heat exchanger installed ahead of the regulating valves to prevent freezing of the valves. The gases are passed through a metering system consisting of two calibrated rotameter flow meters to indicate the proportion of the two gases mixed in the surge tank. As many as eleven lamp assemblies can be operated as a unit, the throughput of the flow meters being chosen accordingly. The tubing which connects the chimney manifold to the chimneys should have an internal diameter not smaller than 1.25 cm. in order to prevent unnecessary restriction in gas flow. The scrubber should have a capacity of about 1 liter. The height of the liquids in the pressure and vacuum regulators is indicated in Fig. 3, and during operation a slow leak of gas through them should be maintained.

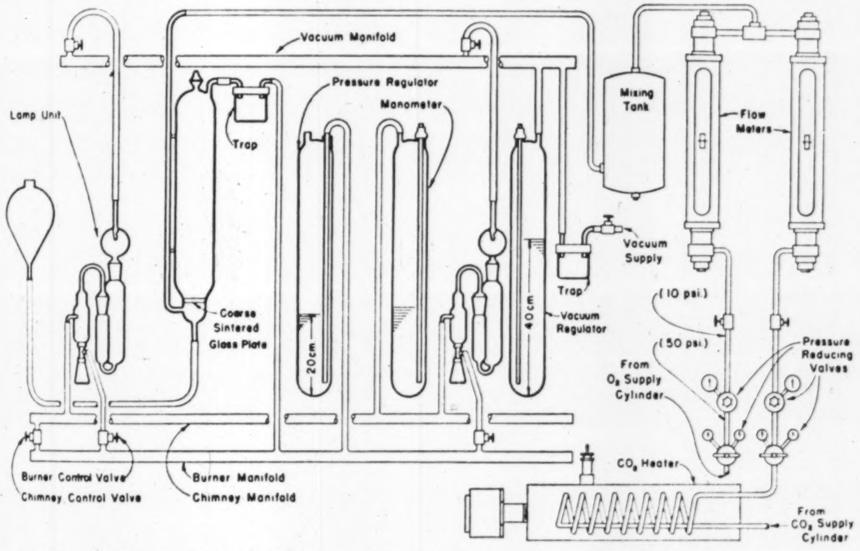
Vacuum Manifold
Pressure Regulator
Manometer
Lamp Unit
Trap
Mixing Tank
Flow Meters
Coarse Sintered Glass Plate
20 cm
40 cm
Vacuum Supply
Trap
Vacuum Regulator
(10 psi.)
(50 psi.)
From O₂ Supply Cylinder
Pressure Reducing Valves
CO₂ Heater
From CO₂ Supply Cylinder
Burner Control Valve
Chimney Control Valve
Burner Manifold
Chimney Manifold

FIG. 3.—Manifold and CO_2-O_2 Supply System for Sulfur Determination.

NOTE 10.—In use, place 300 to 400 ml. of H_2O_2 (3 per cent) in the scrubber. Since the manifold manometer also serves as a scrubber, use H_2O_2 (3 per cent) as the manometric liquid. Replace weekly or whenever the volume becomes less than two thirds of the original.

SUPPLEMENT B

RESULTS OF COOPERATIVE TEST PROGRAM ON DETERMINATION OF SULFUR IN PETROLEUM OILS BY LAMP METHODS

The accompanying Table III summarizes the results of the cooperative program performed to compare the repeatability and reproducibility of A.S.T.M. Method D 90 - 41 T for Test for Sulfur in Petroleum Products by Lamp-Gravimetric Method[3] with a number of alternate procedures which are being used.

Conclusions:

1. Based on the analysis of the detailed data submitted by the eleven participating laboratories, the repeatability

TABLE III.—REPORT OF COOPERATIVE PROGRAM FOR DETERMINATION OF SULFUR BY LAMP METHODS.

Sample	Sulfur Content, Weight Per Cent													
	A.S.T.M. Method D 90-41 T		A.S.T.M. Method D 90 - 41 T (blank for air purification)		A.S.T.M. Method D 90 - 41 T (room or hood scrubbed, air used)		A.S.T.M. Method D 90 - 41 T (combustion atmosphere of O_2-CO_2 for air)		A.S.T.M. Method D 90 - 41 T (O_2-CO_2 for air, sodium alizarin sulfonate as indicator)		A.S.T.M. Method D 90 - 41 T (sample diluted with *n*-heptane)		A.S.T.M. Method D 90 - 41 T (O_2-CO_2 used and sample diluted with *n*-heptane)	
Number Laboratories	6		1		2		5		1		2		2	
Method	Vol.[a]	Grav.[b]	Vol.	Grav.	Vol.	Grav.	Vol.	Grav.	Vol.	Grav.	Vol.	Grav.	Vol.	Grav.
*Iso*octane + Thiophene (known weight per cent of 0.0998 ± 0.0002)	0.105	0.098	0.105	0.092	0.096	0.077	0.096	0.096	0.095	....	....	....	....	....
Catalytically cracked gasoline	0.058	0.042	0.054	0.038	0.044	0.021	0.045	0.039	0.040	....	....	....	....	....
Commercial leaded gasoline (9-lb. Reid vapor pressure)	0.126	0.103	0.129	0.099	0.115	0.086	0.107	0.099	0.099	....	....	....	....	....
Commercial leaded gasoline (12 lb. Reid vapor pressure)	0.127	0.106	0.131	0.109	0.118	0.093	0.108	0.099	0.101	....	....	....	....	....
Thermally cracked gasoline	0.139	0.128	0.136	0.124	0.130	0.103	0.124	0.119	0.126	....	....	....	....	....
Kerosine, (burning rate 350 to 550 ml. per hr.)	0.046	0.042	0.054	0.039	0.042	0.024	0.036	0.038	0.039	....	....	0.035	....	....
No. 1 fuel oil	0.447	0.442	0.431	0.421	0.428	0.406	0.427	0.437	0.430	....	0.446	0.430	0.434 0.440[c] 0.430[d] 0.431[e]	0.424 0.446 0.430 0.431
Reproducibility for gasoline samples	0.006	0.006	....	....	0.005	....	0.003	0.005	....	....	....	....	....	....
Reproducibility for kerosine	0.005	0.004	....	....	0.002	....	0.002	0.003	....	....	....	....	....	....
Reproducibility for No. 1 fuel oil	0.014	0.014	....	....	0.004	....	0.003	0.004	....	....	0.021	0.004	0.002	0.010

[a] Volumetric.
[b] Gravimetric.
[c] Proposed Method of Test for Sulfur in Petroleum Oils by Quartz Tube Combustion, Appendix VII, A.S.T.M. Standards on Petroleum Products and Lubricants, 1948 (one laboratory).
[d] A.S.T.M. Method D 90 - 41 T with O_2-CO_2 substituted for air and I.P. type burner used (one laboratory).
[e] A.S.T.M. Method D 90 - 41 T with I.P. type burner used (one laboratory).

of the different lamp methods varied between 0.001 and 0.005 weight per cent sulfur. The value of 0.001 weight per cent for the oxygen-carbon dioxide procedure was measurably better than the other procedures.

2. Based on the above summary, the reproducibility of the different lamp methods varied between 0.003 and 0.009 weight per cent sulfur. The value of 0.003 weight per cent for the oxygen-carbon dioxide was measurably better than the other procedures.

3. There was a constant difference of approximately 0.01 weight per cent sulfur between the volumetric and gravimetric methods which employed air as a burning medium. This difference indicates the presence of a systematic error.

APPENDIX VII

PROPOSED METHOD OF TEST FOR BOILING POINT RANGE OF POLYMERIZATION GRADE BUTADIENE[1,2]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pa.

Scope

1. This method is intended for the determination of the boiling point range of polymerization grade butadiene. Butadiene dimer and residue, when present, contribute to an abnormal rise in the boiling temperature and, therefore, these components must be removed.

Outline of Method

2. A 40-ml. sample is distilled in a specially designed Cottrell still. Boiling points are observed at the 2-ml. and 0.5-ml. residual volumes. When the boiling point difference between these residual volumes is greater than 0.4 C., the determination is repeated on a sample prepared to eliminate the interference of the dimer and residue.

Apparatus

3. (*a*) The apparatus shall be assembled as shown in Fig. 1 and shall consist of a vacuum-jacketed Cottrell still from which the sample can be distilled (or evaporated by distillation). Complete constructional details are given in Snpplement A.

(*b*) *Thermometer.*—The thermometer shall conform to the specifications as given in Supplement B.

Apparatus Preparation

4. When cleaning the apparatus, carefully remove the pump and clean it separately. Clean both still and pump with chromic acid cleaning solution, rinse thoroughly with distilled water, and dry in an oven. Benzene or trichloroethylene, followed by acetone, are good cleaning solvents to use between tests.

Procedure

5. (*a*) Invert the sample cylinder to allow sample to be taken from the liquid phase. Chill the still without the pump in place by rinsing with liquid sample. Carefully replace the pump and introduce liquid sample to the 40-ml. mark within plus or minus 0.5 ml.

(*b*) Wipe the frost from the still with a dry towel, and insert the still into the vacuum jacket. Carefully secure the still and vacuum jacket with the springs. Insert the thermometer and adjust it so that the top of the mercury bulb is even with the outlet of the pump. Clamp the unit in place with the ball of the heater wire resting in the socket of the heater.

(*c*) Turn on the heater at the beginning of the distillation to obtain boiling

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[1] This proposed method is under the jurisdiction of the A.S.T.M. Committee D-2 on Petroleum Products and Lubricants. Published as information, October, 1949.

[2] This method was developed and has been cooperatively tested by the Butadiene Producer's Committee on Specifications and Methods of Analysis of the Office of Rubber Reserve. It appears in the Butadiene Laboratory Manual, Office of Rubber Reserve, as Method No. 2.1.7.2.

in the still, and adjust the boiling rate so that the last 10 ml. of the sample will distill in 15 ± 2 min.

(*d*) Record the temperatures at the residual liquid volumes of 2.0 ml. and 0.5 ml. Should the temperature rise between residual volumes of 2.0 ml. and 0.5 ml. be greater than 0.4 C., remove the dimer and nonvolatile matter as described in A.S.T.M. Methods D 1024 and D 1025, Tests for Butadiene Dimer and Nonvolatile Residue in Polymerization Grade Butadiene,[3] and repeat the test as described in Paragraphs (*a*) to (*c*).

(*e*) Report the temperature rise to the nearest 0.1 C. If the sample was treated to remove butadiene dimer and nonvolatile matter, report results only for the treated sample.

Precision

6. Results should not differ from the mean by more than the following amounts:

Residual Volumes	Temperature Differences, deg. Cent.	
	Repeatability, One Operator and Apparatus	**Reproducibility,** Different Operators and Apparatus
0.5-ml.	0.1	0.2
2-ml.	0.1	0.2

---

[3] 1949 Book of A.S.T.M. Standards, Part 5.

SUPPLEMENT A

APPARATUS

Apparatus:

A1. The apparatus shall be assembled as shown in Fig. 1 and shall consist of the following:

(*a*) *Still*, constructed of heat-resistant glass and conforming to the dimensions shown in Fig. 2(*a*). The still shall be graduated as follows, starting at the bottom of the still: the first milliliter shall be calibrated at 0.2-ml. intervals; the next 10 ml. at 1-ml. intervals; and the balance of the still at 20, 30, and 40 ml., all calibrations to be made with the thermometer and pump in place. A tungsten tip shall be sealed into the bottom of the still.

(*b*) *Lift Pump*, constructed from heat-resistant tubing 2 mm. in outside diameter and conforming to the dimensions shown in Fig. 2(*b*), being flattened on the bottom to a diameter of 10 mm. A glass ring shall be sealed on top to hold the pump at a proper distance from the thermometer bulb.

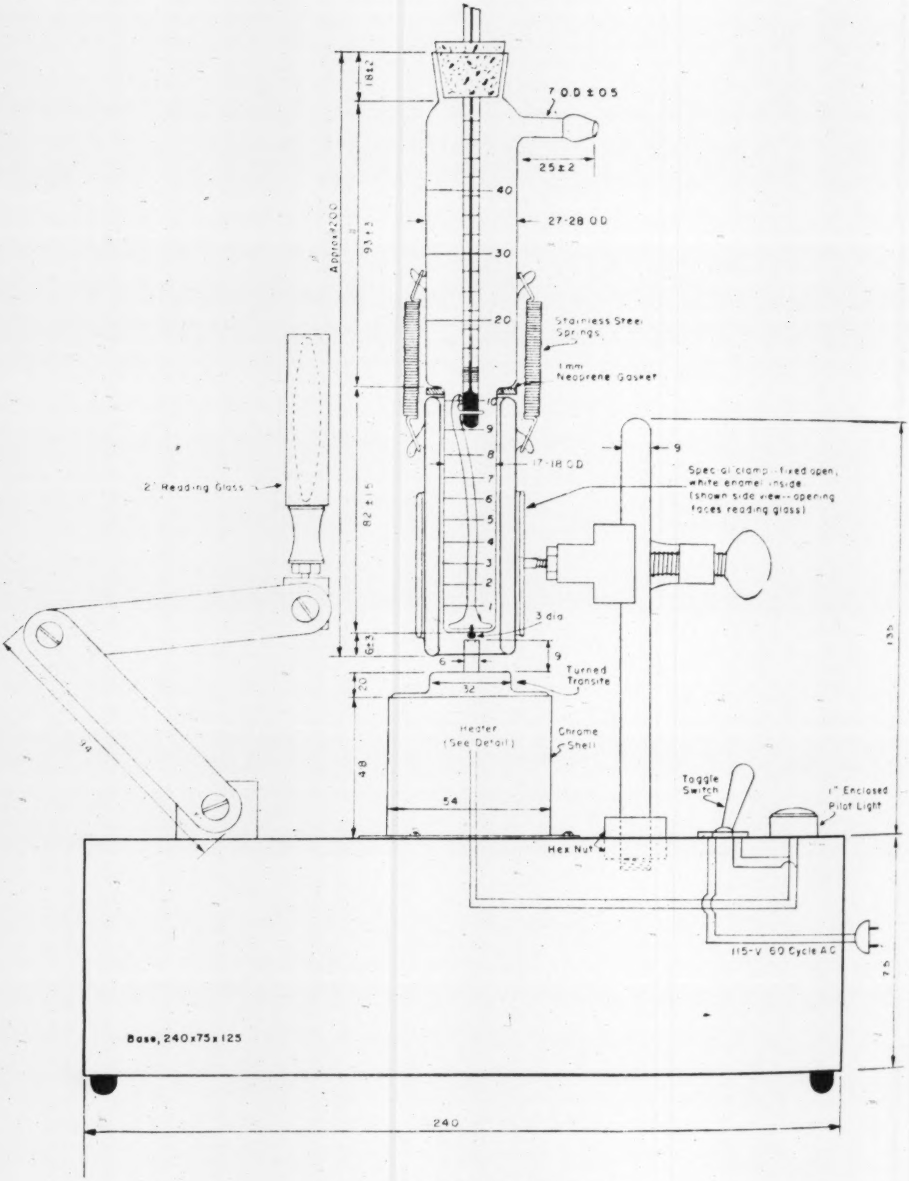
(*c*) *Vacuum Jacket*, constructed to conform to the dimensions shown in Fig. 2(*c*), to fit over the lower portion of the still. A neoprene rubber gasket shall be provided for use between the top of the jacket and the still. The jacket and the still shall be held firmly together by two stainless steel springs.

(*d*) *Heating Element and Stand* conforming to the dimensions and specifications shown in Figs. 1 and 3 and consisting of a cartridge heater,[4] 150-v. 30-w., placed in a transite block 54 mm. in diameter and 64 mm. high. A copper sleeve and conductor tip, 6 mm. in diameter at the top, shall be fitted over the cartridge heater. The heater shall be mounted on a suitable base, 250 mm. long, 75 mm. high, and 125 mm. wide and shall be wired through a toggle switch and pilot lamp.

(*e*) *Accessories.*—To the base, Fig. 1, shall be mounted a steel rod 9 mm. in diameter and 135 mm. high to which shall be fastened a special clamp that is white enameled inside and capable of holding the vacuum jacket securely. The clamp shall be open at the front so that the boiling can be observed. A 2-in. diameter reading glass shall be mounted in front of the still. The support for this glass may be of any convenient design so that the glass can be adjusted upward or downward to permit reading the thermometer at any temperature.

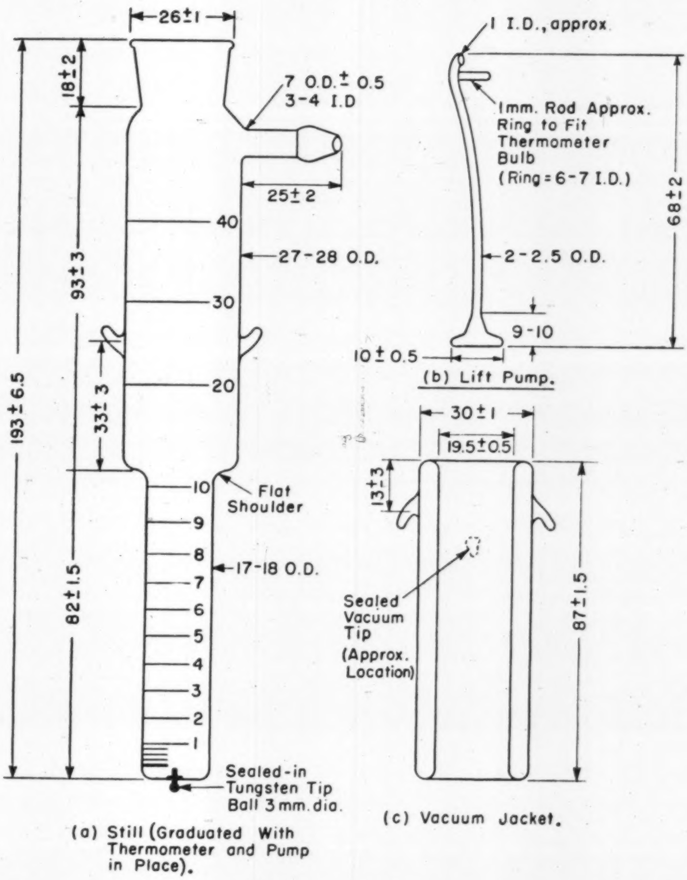
---

[4] A General Electric Co. cartridge heater No. 2A63 has been found satisfactory for this purpose.


18±2
7 O.D ± 0.5
25±2
Approx 200
93±3
40
27-28 OD
30
20
Stainless Steel Springs
1 mm Neoprene Gasket
10
9
8
7
6
5
4
3
2
1
17-18 OD
82±15
2" Reading Glass
9
Special clamp—fixed open, white enamel inside (shown side view—opening faces reading glass)
3 dia
6±3
6
9
Turned Transite
20
32
Heater (See Detail)
Chrome Shell
48
54
94
135
Toggle Switch
1" Enclosed Pilot Light
Hex Nut
115-V 60 Cycle AC
75
Base, 240x75x125
240

NOTE.—All dimensions in millimeters.

FIG. 1.—Assembled Butadiene Boiling Range Apparatus.


26±1
18±2
7 O.D.± 0.5
3-4 I.D
25±2
40
27-28 O.D.
93±3
30
33±3
20
193±6.5
10
Flat Shoulder
9
8
17-18 O.D.
7
6
82±1.5
5
4
3
2
1
Sealed-in Tungsten Tip Ball 3 mm. dia.
1 I.D., approx.
1mm. Rod Approx. Ring to Fit Thermometer Bulb (Ring = 6-7 I.D.)
68±2
2-2.5 O.D.
9-10
10±0.5
30±1
19.5±0.5
13±3
Sealed Vacuum Tip (Approx. Location)
87±1.5

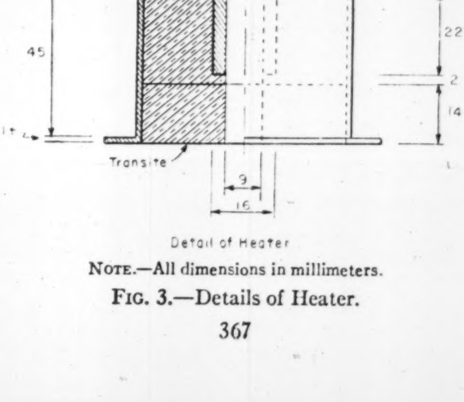
(a) Still (Graduated With Thermometer and Pump in Place).

(b) Lift Pump.

(c) Vacuum Jacket.

NOTE.—All dimensions in millimeters.

FIG. 2.—Details of Butadiene Boiling-Range Apparatus.


Copper Shell and Conducter Tip Over Cartridge Heater
G.E. #2A63 Cartridge Heater, 115-V, 30-W
6
29
45
9
19
9
22
2
14
Transite
9
16
Detail of Heater

NOTE.—All dimensions in millimeters.

FIG. 3.—Details of Heater.

SUPPLEMENT B

REQUIREMENTS FOR BUTADIENE BOILING POINT RANGE THERMOMETER

Name	**A.S.T.M. Butadiene Boiling Point Range**
Liquid	mercury
Filling above Liquid	nitrogen gas
Temperature Range	−10 to +10 C.
Subdivisions	0.1 C.
Total Length	160 ±3 mm.
Stem Diameter	6.0 to 6.5 mm.
Bulb Diameter	5.5 mm. minimum to not greater than stem diameter
Bulb Length	9 to 13 mm., max.
Bottom of Bulb to Graduation Line at	−10 C.
Distance	28 to 36 mm.
Top of Thermometer to Graduation Line at	+10 C.
Distance	35 to 51 mm.
Expansion Chamber	long narrow type to permit heating to 100 C. Length of unchanged capillary between highest graduation and base of expansion chamber shall be not less than 10 mm.
Top Finish	plain
Graduation Lines at Each	0.5 C.
Graduations Numbered at Each Multiple of	1.0 C.
Immersion	total
Marking on Thermometer	ASTM BUTA BPR
Scale Error at any Point when Standardized Shall not Exceed	0.1 C.
Marking on Case	A.S.T.M. Butadiene Boiling Point Range Thermometer, −10 to +10 C.

APPENDIX VIII

PROPOSED METHODS OF TEST FOR PHOSPHORUS IN LUBRICATING OILS, LUBRICATING OIL ADDITIVES, AND THEIR CONCENTRATES[1]

These proposed methods are published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pa.

Scope

1. These methods are applicable to the determination of phosphorus in unused lubricating oils, lubricating oil additives, and their concentrates. The methods are not restricted with respect to the type of phosphorus compounds that may be present—for example, tri- or pentavalent phosphorus compounds, phosphines, phosphates, phosphonates, phosphorus sulfides, etc.—since all are quantitatively converted to an aqueous solution of orthophosphate ion by oxidation of the sample during the course of analysis.

Outline of Method

2. Organic material in the sample is removed and the phosphorus is converted to phosphate ion by oxidation with sulfuric acid, nitric acid, and hydrogen peroxide. One of two procedures is then followed:

	Sections
Photometric (Molydivanado) Method.	4 to 15
Gravimetric Method................	4 to 8 and 16 to 22

The photometric method is used where the phosphorus content is estimated to be under 2 per cent, and the gravimetric method for phosphorus contents of 2 per cent or over.

Purity of Reagents and Water

3. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications on analytical reagents established by the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. References to water shall be understood to mean distilled water.

OXIDATION OF THE SAMPLE

Scope

4. This method describes a procedure for removal of organic material and subsequent conversion of phosphorus to phosphate ion in samples of unused lubricating oils, lubricating oil additives, and their concentrates.

Outline of Method

5. Organic material in the sample is removed and the phosphorus is converted to phosphate ion by oxidation with sulfuric acid, nitric acid, and hydrogen

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[1] This proposed method is under the jurisdiction of the A.S.T.M. Committee D 2 on Petroleum Products and Lubricants. Published as information, October, 1949.

It is anticipated by the committee that this method will replace the Tentative Method of Chemical Analysis for Phosphorus in Lubricating Oils (A.S.T.M. Designation: D 809), 1949 Book of A.S.T.M. Standards, Part 5.

peroxide. The residual hydrogen peroxide is removed by diluting with water and evaporating several times to dense white fumes.

Apparatus

6. The apparatus shall consist of the following:

(*a*) *Digestion Flasks.*—Kjeldahl flasks, 300-ml., ground-glass stoppered.

(*b*) *Digestion Rack.*—A digestion rack constructed to hold one or more 300-ml. Kjeldahl flasks at an angle of approximately 45 deg. in such a fashion that direct heat is applied only to the bottom of the flask and such that the body and neck of the flask are insulated from the source of heat. Approximately three fourths of the neck of the flask should be cooled by air at atmospheric temperature, preferably by directing an air stream against the neck of the flask. A bunsen flame or high-capacity electric heater are suitable heat sources.

Reagents

7. (*a*) *Hydrogen Peroxide (30 per cent)*, containing no more than 0.00002 per cent phosphorus.

(*b*) *Nitric Acid (sp. gr. 1.42).*

(*c*) *Sulfuric Acid (sp. gr. 1.84).*

Procedure

8. (*a*) Weigh out a portion of the material to be analyzed, in accordance with Table I, into a 300-ml. Kjeldahl flask. Any convenient method of transferring the sample may be used as long as care is taken to avoid getting the sample on the neck of the flask (Note 1). Add H_2SO_4 (3 ml. for the photometric procedure, or 10 ml. for the gravimetric procedure) and a 6-mm. glass bead (Note 2), and swirl the flask to mix the contents.

(*b*) Make a blank determination following the same procedure and using the same amounts of all reagents and a similar size sample of phosphorus-free white oil. This blank is for use in the photometric method (Sections 9 to 15).

NOTE 1.—In order to obtain satisfactory accuracy with the small amounts of phosphorus involved, it is necessary to take extensive precautions in handling. The usual precautions of cleanliness, careful manipulation, and avoidance of contamination should be scrupulously observed; also, all glassware should be cleaned before use, with cleaning acid or by some procedure that does not involve use of commercial detergents. These compounds often contain alkali phosphates which are strongly adsorbed by glass surfaces and are not removed by ordinary rinsing. It is desirable to segregate a special stock of glassware for use only in the determination of phosphorus.

TABLE I.—SAMPLE SIZE.

Phosphorus Content, per cent	Approximate Weight of Sample, g.	Precision of Weighing, plus or minus, g.
PHOTOMETRIC (MOLYBDIVANADO) METHOD		
0.002 to 0.2	2	0.004
0.2 to 2	0.2	0.0004
GRAVIMETRIC METHOD		
2 to 5	2	0.004
5 to 10	1	0.003
10 to 15	0.7	0.002
15 to 25	0.4	0.001

NOTE 2.—The volume occupied by the glass bead (0.1 ml.) may be ignored for ordinary work. Excessive bumping is encountered occasionally in the digestion of some organic phosphorus compounds. This bumping may be minimized by using a glass bead. Some difficulty may be experienced when using commercial "bumping aids" in obtaining a solution clear enough for photometric measurement of phosphorus (Sections 8 to 14) even after centrifuging, due to the attrition of these "bumping aids" under the vigorous digestion procedure.

Place the flask on the digestion rack under a hood and warm gently with a micro burner until the sample is charred, while cooling the neck of the flask, preferably by use of an air stream (Note

3). Continue heating until dense white fumes appear (Note 4). While boiling, continuously add 1 ml. of HNO_3 dropwise (Note 5) to oxidize the organic material. When the HNO_3 has boiled off and dense white fumes reappear, repeat the treatment with an additional 1 ml. of HNO_3 (Note 6). Continue the addition of HNO_3 in 1-ml. increments until the digestion mixture is no darker than a straw color, indicating that almost all the organic matter has been oxidized.

NOTE 3.—The amount of air used to cool the neck of the flask will at times have to be reduced or even shut off to allow vapors and fumes to leave the flask and to allow the sample to come to dense white fumes. However, this should not be done until the sample is in a well-decomposed state; the air stream should be turned on again each time before the addition of the HNO_3 or H_2O_2 (Paragraph (*c*)).

NOTE 4.—Excessive evaporation of H_2SO_4 should be avoided to minimize any loss of phosphorus that may occur. Care should be exercised to avoid heating above the liquid level. Since there is some indication that with samples containing inorganic compounds (that is, barium or lead salts) there may be losses of phosphorus due to sintering or fusion of the phosphate and sulfate to the glass, it is well to examine the dried vessel after use to detect any opaque film of fused material.

NOTE 5.—Unless the HNO_3 is added dropwise, it may force excessive amounts of vapor from the flask and lead to loss of phosphorus-containing fumes.

NOTE 6.—In order to minimize the loss of H_2SO_4 in the dissolution process, it is advisable not to carry the digestion mixture to dense fumes between additions of HNO_3.

(*c*) Cool the flask slightly and add 10 drops (0.5 ml.) of H_2O_2. Heat until dense white fumes appear, and, while boiling, cautiously add 1 ml. of HNO_3 dropwise. When the HNO_3 has boiled off and dense white fumes reappear, repeat the treatment with H_2O_2 and HNO_3 until the digestion mixture is colorless, at which time the organic material will be completely oxidized. Four treatments will usually suffice. The total amount of H_2O_2 used should be noted, and the same amount used for each sample and the blank.

(*d*) When oxidation is complete, allow the flask to cool, wash down the mouth and neck with a minimum amount of water (5 ml.), and mix the contents. Return the flask to the digestion rack and continue heating to the appearance of dense white fumes. Repeat the process of the addition of water and heating to dense fumes several times. This will remove all traces of H_2O_2 (Note 7).

NOTE 7.—Extreme care must be used, in fuming in accordance with Paragraph (*d*), to remove all traces of H_2O_2 in order that no color interference will be experienced when phosphorus is to be determined photometrically, as described in Sections 9 to 15.

PHOTOMETRIC (MOLYBDIVANADO) METHOD

Scope

9. This method is intended for the determination of total phosphorus in concentrations of under 2 per cent (Note 8), calculated on the basis of the original sample, in samples treated by the acid-oxidation procedure described in Sections 4 to 8.

NOTE 8.—For phosphorus concentrations of 2 per cent and over, see Sections 16 to 22.

Outline of Method

10. After oxidation of organic material in the sample and quantitative conversion of the phosphorus to the phosphate ion, the acidity of the digestion mixture is adjusted and the mixture diluted to suitable volume. Solutions of ammonium vanadate and ammonium molybdate are added in the order named. The addition of the molybdate solution to the acid vanadate-phosphate mixture results in the formation of a heteropoly acid, molybdivanadophosphoric acid, which is

yellow in color. Although the exact composition of molybdivanadophosphoric acid is uncertain, solutions of this compound, when formed in accordance with carefully prescribed conditions, have been found to conform to the Beer-Lambert Law for optical transmittance measurements made at 420 to 470 mμ as a function of phosphorus content.

Apparatus

11. *Photoelectric Photometer.*—A grating-type spectrophotometer capable of isolating a 5-mμ spectral band at 430 and 460 mμ is a suitable instrument for use in this determination. The instrument should be equipped with auxiliary facilities for handling 1, 2, and 5-cm. cells, and a supply of these should be available. Other instruments such as photoelectric filter photometers may also be used (Note 9).

Note 9.—While not as desirable as photometers, visual color comparators can also be used, if necessary.

Reagents

12. (*a*) *Ammonium Molybdate Solution.*—Dissolve 50 g. of $(NH_4)_2MoO_4$ in warm water and dilute to 1 liter. Filter before using.

(*b*) *Ammonium Vanadate Solution.*—Dissolve 2.5 g. of NH_4VO_3 in 500 ml. of hot water, add 20 ml. of HNO_3 (sp. gr. 1.42), and dilute to 1 liter.

(*c*) *Phosphate Solution* (*Standard, 1 ml. = 0.1 mg. P*).—Dissolve 0.4393 g. of KH_2PO_4 in water and dilute to 1 liter. For best work, the salt should be twice recrystallized and vacuum-dried before use.

(*d*) *Sulfuric Acid* (*sp. gr. 1.84*).

Preparation of Calibration Curves

13. (*a*) Introduce 0, 0.4, 0.8, 1.6, 2.4, 4.0, 4.8, 8.0, 16, 24, and 32 ml. of standard phosphate solution into 100-ml. ground-glass-stoppered volumetric flasks. Add sufficient H_2SO_4 of any convenient concentration such that the final acid concentration after dilution to 100 ml. will be 0.5 *N*. Dilute to 55 to 60 ml. and add 10 ml. each of ammonium vanadate solution and ammonium molybdate solution, in the order named, with adequate mixing between additions. Dilute to 100 ml., close with a ground-glass stopper, and mix thoroughly. Allow to stand at least 30 min. to develop the color.

(*b*) Using the 1-cm. cell and with the wave length set at 460 mμ, adjust the photometer to read 100.0 per cent transmittance with the zero phosphate (reagent blank) standard. Although optical cells are usually very closely matched, for best work it is recommended that two cells be used and that one be reserved for the blank; the other for the standard or sample solutions. Obtain transmittance measurements on solutions containing 0.4, 0.8, 1.6, 2.4, and 3.2 mg. of phosphorus. These standards should give measurements falling between 90 and 20 per cent respectively. After making a measurement, return to the reagent blank cell. This should check the 100.0 per cent setting within 0.2 per cent. Repeat the reading of the standard and return to the blank. Obtain three readings in all on each standard solution. Using semilog graph paper, plot the average transmittance as a function of phosphorus content. The resultant curve should be a straight line.

(*c*) In a similar manner, prepare calibration curves at 460 mμ for the 2- and 5-cm. cells, selecting concentrations from the series of standards that give readings between 20 and 90 per cent.

(*d*) Finally, prepare a calibration curve for the 5-cm. cell, using a wave length setting of 430 mμ. At this wave length the molybdivanadophosphoric acid has a higher optical density, and the curve obtained will have a steeper slope. The advantages of having this calibration at the second wave length are two-fold: (*1*) it provides increased sensitivity in the region of low concentrations, and (*2*) it provides an independent confirmation of measurements made at 460 mμ. Agreement between measurements at both wave lengths is a criterion of the absence of interference.

Procedure

14. (*a*) To the cooled, decomposed sample in the Kjeldahl flask (Section 8 (*d*)), add by visual observation sufficient H_2SO_4 to bring the acidity to approximately one half the concentration present at the beginning of the acid-oxidation procedure (Section 8 (*a*)). This step may not always be necessary (Note 10). Cool the flask and contents and transfer to a 100-ml. volumetric flask, using approximately 50 ml. of water (Note 11).

NOTE 10.—The acidity of the solution after acid oxidation is critical, since interference occurs from the appearance of an orange-yellow color which forms in a neutral or too acid solution. The acidity for proper development of the desired color should be in the range of 0.2 *N* to 1.0 *N* in H_2SO_4 (optimum 0.5 *N*). Adjustment of acidity may not be required if the losses of H_2SO_4 have been kept to a minimum in the fuming steps of the acid-oxidation procedure; however, it may be necessary to further evaporate H_2SO_4 in order to bring the acidity of the solution to approximately optimum normality.

NOTE 11.—Extreme care must be exercised when adding water to H_2SO_4. It is advisable to add the water slowly, a small amount at a time, allowing it to run down the side of the flask which is adequately cooled.

(*b*) Add 10 ml. each of ammonium vanadate solution (Note 12) and ammonium molybdate solution. It is important that these solutions be added in the order named, with adequate mixing between additions, to ensure the reproducible composition of the complex. Dilute to 100 ml., stopper with a ground-glass stopper, and mix thoroughly. Allow to stand at least 30 min. for development of color. This is the minimum time allowed before measurement. Since the color is stable for at least a week or longer, there is no maximum time limit before which measurements must be made.

NOTE 12.—Very little H_2O_2 is required to develop the maximum color of the vanadium-hydrogen peroxide complex. Any trace of H_2O_2 will be evident by the reddish brown color obtained upon the addition of the vanadium reagent. If such is the case the sample must be discarded and the acid-oxidation step will have to be repeated on a new sample.

(*c*) If any insoluble matter is present, transfer a portion of the solution to a centrifuge tube, centrifuge at 1200 rpm. for 5 min., and decant the clear supernatant liquid into the optical cell. If desired, a portion of the solution may be drawn off by means of a filter stick. Avoid the use of filter paper as the colored complex may be adsorbed on it.

(*d*) If the approximate phosphorus content is known, transfer to the optical cell a portion of the clear solution that will give a transmittance between 30 and 70 per cent. It is desirable to employ conditions such that readings fall on the central portion of the scale, since maximum accuracy can not be achieved when galvanometer readings are either very high or very low. If the phosphorus content is unknown, the analyst will find that with experience he is able to select the best cell to use by visual observation. In the case of samples that prove to be too highly colored to be read directly, transfer an appropriate aliquot to another volumetric flask and dilute with the reagent blank solution in order to maintain all the reagent concentrations at the proper level. Make all measurements at 460 mμ except for the extremely low concentrations (below 0.25 mg. P per 100 ml.), measurements which shall be made at both 430 mμ and 460 mμ. In making the readings, adjust the galvanometer reading to 100.0 per cent with the reagent blank solution in the light path. Insert the sample in the light path, read the percentage transmittance to 0.1 per cent, and return to the reagent blank which should check the original setting within 0.2 per cent. Readjust to 100.0 if necessary and repeat, obtaining at least three readings on the samples. These should agree within 0.2 per cent. Use the average of these readings to obtain the phosphorus content from the calibration curves.

(*e*) *Over-all Blank.*—Although a reagent blank solution is used in preparing the calibration curves, an over-all blank determination should be carried through on a sample of phosphorus-free white oil. No phosphorus should be detectable in such a blank.

Calculation

15. Calculate the percentage of phosphorus as follows:

$$\text{Phosphorus, per cent} = \frac{(P_s - P_b) \times D \times 100}{1000 \times S}$$

where:

P_s = milligrams of phosphorus in sample read from standard curve,

P_b = milligrams of phosphorus in over-all blank read from standard curve,

D = dilution factor, if an aliquot is used (Section 14 (*d*)), and

S = grams of sample used.

GRAVIMETRIC METHOD[2]

Scope

16. This method is intended for the determination of total phosphorus in concentrations of 2 per cent and over (Note 13), calculated on the basis of the original sample, in samples treated by the acid-oxidation procedure described in Sections 4 to 8.

NOTE 13.—For phosphorus concentrations under 2 per cent, see Sections 9 to 15.

Outline of Method

17. After oxidation of organic material in the sample and quantitative conversion of the phosphorus to the phosphate ion, the phosphate ion is separated from interfering metals by precipitation as ammonium molybdiphosphate in nitric acid solution. After an ammoniacal solution of the phosphate ion is obtained, the phosphorus is precipitated as magnesium ammonium phosphate, ignited, and weighed as magnesium pyrophosphate.

Apparatus

18. *Electric Muffle Furnace.*—The furnace shall be capable of operating over a variable temperature range of 200 to 1100 C. and of maintaining a temperature of 1050 ± 50 C.

Reagents

19. (*a*) *Ammonium Hydroxide* (*sp. gr. 0.90*).

(*b*) *Ammonium Hydroxide* (*3:5*).—Mix 3 volumes of NH_4OH (sp. gr. 0.90) with 5 volumes of water.

(*c*) *Ammonium Hydroxide* (*1:24*).—Mix 1 volume of NH_4OH (sp. gr. 0.90) with 24 volumes of water.

(*d*) *Ammonium Nitrate,* NH_4NO_3 crystals.

(*e*) *Ammonium Nitrate Solution.*—Dissolve 50 g. of NH_4NO_3 in water and dilute to 1 liter.

(*f*) *Hydrochloric Acid* (*sp. gr. 1.18*).

(*g*) *Magnesia Mixture.*—Dissolve 50 g. of $MgCl_2 \cdot 6H_2O$ and 100 g. of NH_4Cl in 500 ml. of water, add a slight excess of NH_4OH, and allow to stand overnight. Filter, make the solution just acid with HCl, and dilute to 1 liter.

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[2] Prepared from the "Proposed Method of Test for Phosphorus in Organic Materials (Acid-Oxidation Method)," published as information in *Proceedings*, Am. Soc. Testing Mats., Vol. 46, p. 352 (1946).

(*h*) *Molybdate Reagent.*—Dissolve 100 g. of $(NH_4)_2 MoO_4$ in 400 ml. of water. Add 80 ml. of NH_4OH (sp. gr. 0.90) and filter if a precipitate appears. Mix 400 ml. of HNO_3 (sp. gr. 1.42) with 600 ml. of water. Prepare the ammonium molybdate reagent from these solutions immediately before use by slowly mixing one volume of the ammonium molybdate solution with two volumes of the diluted HNO_3, while stirring rapidly.

(*i*) *Nitric Acid* (*1:1*).—Mix equal volumes of HNO_3 (sp. gr. 1.42) and water.

Procedure for Samples Containing no Metals Other than Alkali Metals

20. (*a*) Cool the Kjeldahl flask (Section 7(*d*)), transfer the solution to a 400-ml. beaker, and wash the flask with small portions of water until the volume of solution is approximately 100 ml. Boil the solution for 5 to 10 min., cool to near room temperature, and add NH_4OH (sp. gr. 0.90) until the solution is neutral to methyl red. Make the solution acid with HCl (sp. gr. 1.18) and add 1 ml. in excess.

(*b*) Add 20 ml. of magnesia mixture, slowly and while stirring, and cool the solution to below room temperature in an ice bath. Add NH_4OH (sp. gr. 0.90), slowly and while stirring constantly, until the solution is basic. Continue stirring until most of the precipitate has formed (Note 14); then add 5 ml. of NH_4OH (sp. gr. 0.90) in excess. Allow the precipitate to stand overnight, filter through a weighed porcelain filter crucible of fine porosity, wash with NH_4OH (1:24), and dry in an oven. Place in a cool furnace, gradually raise the temperature to red heat, and ignite at 1050 ± 50 C. for 30 to 40 min. Repeat the ignition for similar periods until constant weight is reached.

NOTE 14.—For work of highest accuracy, it is generally necessary to test the precipitation technique on known inorganic samples. Reprecipitation sometimes aids in obtaining more accurate values.

Procedure for Samples Containing Metals Other than Alkali Metals

21. (*a*) Cool the Kjeldahl flask (Section 7(*d*)), add 40 to 50 ml. of water, cool to room temperature, and filter the solution through a medium-texture, ashless paper. Collect the filtrate in a 500-ml. wide-mouth, glass-stoppered Erlenmeyer flask, and wash the Kjeldahl flask and filter paper thoroughly with water; discard the paper. Boil the solution for several minutes and cool to near room temperature. Add NH_4OH (sp. gr. 0.90) until the solution is neutral to methyl red; then add HNO_3 (1:1) until the color just changes to red. Concentrate or dilute the solution to approximately 150 ml.

(*b*) Add 15 g. of NH_4NO_3 crystals and swirl until dissolved. Adjust the temperature to 35 to 40 C. and add 120 ml. of freshly prepared molybdate reagent. Stopper the flask, shake vigorously for 4 to 6 min., and allow to stand for at least 2 hr., or preferably overnight. Filter the solution through a medium-texture, ashless paper. Wash the precipitate with NH_4NO_3 solution. Do not attempt to transfer all of the precipitate from the flask to the paper; however, reserve the flask for later treatment. Wash the precipitate several times with the wash solution but do not allow the stream of wash solution to strike the funnel above the edge of the paper as the precipitate has a tendency to creep.

(*c*) Place a clean 400-ml. beaker under the funnel and dissolve the precipitate through the paper into the beaker with NH_4OH (3:5). Use a little of the NH_4OH to dissolve any of the precipitate that remained in the flask set aside in Paragraph (*b*) and pour this solution through the paper. Wash the flask, funnel, and paper four times with hot water, once with NH_4OH (3:5), and once again with water. Discard any residue remaining on the paper. Evaporate the solution to a volume of 90 to 100 ml., make the solution acid with HCl, and add 1 ml. in excess. Disregard any molybdiphosphate precipitate that may appear at this point.

(*d*) Add 10 ml. of magnesia mixture slowly, while stirring, and cool the solution to below room temperature in an ice bath. Add NH_4OH (sp. gr. 0.90) slowly, while stirring constantly, until the solution is basic. Continue stirring until most of the precipitate has formed, then add 5 ml. of NH_4OH (sp. gr. 0.90) in excess. Allow the precipitate to stand overnight.

(*e*) Filter through a weighed porcelain filter crucible (fine porosity), wash with NH_4OH (1:24), and dry in an oven. Place in a cool furnace, gradually raise the temperature to red heat, and ignite at 1050 ± 50 C. for 30 to 40 min. Repeat the ignition for similar periods until constant weight is reached.

Calculation

22. Calculate the percentage of phosphorus as follows:

$$\text{Phosphorus, per cent} = \frac{P \times 27.84}{W}$$

where:

P = grams of magnesium pyrophosphate, and

W = grams of sample used.

SUMMARY OF RESULTS OF COOPERATIVE TESTS

The results of cooperative tests on these proposed methods for phosphorus, and a statistical analysis of the data, are given in Tables II and III.

TABLE II.—SUMMARY OF RESULTS OF COOPERATIVE TESTS ON THE PROPOSED ACID OXIDATION —GRAVIMETRIC METHOD FOR PHOSPHORUS.

Laboratory[a]	Phosphorus, per cent		
	Sample S-156	Sample S-159	Sample S-165
A	3.32	9.37	2.07
	3.35	9.37	2.07
	3.33	9.42	
	3.33		
	Avg. 3.33	9.39	2.07
B	3.71	9.69	2.09
	3.83	9.66	2.08
		9.66	
	Avg. 3.77	9.67	2.09
C	3.38	9.47	2.06
	3.37	9.50	2.00
	Avg. 3.38	9.49	2.03
D	3.16	9.44	2.07
	3.21	9.50	2.10
	Avg. 3.19	9.47	2.09
E	3.40	9.75	2.76[d]
	3.41	9.64	2.80[d]
	Avg. 3.41	9.70	2.78
F	3.39	9.61	2.10
	3.33	9.79	2.11
	Avg. 3.36	9.70	2.11
G	3.40	9.93	2.02
	3.48	9.36	1.98
	Avg. 3.44	9.64	2.00
Summary:[c]			
N	16	16	12
$\bar{P}$	3.40	9.57	2.06
σ_p	0.165	0.169	0.041
$100\,\sigma_p/\bar{p}$	4.84	1.77	2.01

Laboratory[b]	Phosphorus, per cent				
	Sample S-77	Sample S-78	Sample S-27	Sample S-48B	Sample S-49B
C			12.82	11.72	
			12.80	11.74	
F	21.30	10.97	12.99	11.92	8.55
	21.39	10.91	12.92	12.02	8.50
		10.94	12.83	12.12	
			12.83		
G	21.92	10.98	(a) 13.08[e]	(a) 11.83[e]	(a) 8.37[e]
	21.85	10.97	13.10	11.83	8.45
	22.06	11.13	13.07	11.83	8.41
	22.00	11.11	(b) 13.26	(b) 11.91	(b) 8.56
			13.04	11.89	8.50
			13.29		
H	22.09	10.98	13.11	11.55	8.31
	21.86	10.96	13.10	11.34[d]	8.11
K	22.00	11.06	13.08	11.90	8.45
	22.05	11.10	13.11	11.99	8.37
		10.91			
		10.87			
		10.81			
		10.89			
		11.01			
L			13.00		
			13.00		
M		10.97			
		10.91			
		10.94			
Summary:[c]					
N	10	19	18	13	11
$\bar{P}$	21.85	10.969	13.025	11.865	8.416
σ_p	0.280	0.083	0.142	0.145	0.128
$100\,\sigma_p/\bar{p}$	1.28	0.76	1.09	1.22	1.52

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[a] Low range reported in Lykken's letter of September 3, 1946.

[b] High range reported in Lykken's letter of October 8, 1945.

[c] The symbols used in this summary are defined as follows:

N = number of individual determinations averaged,

$\bar{P}$ = arithmetic average,

σ_p = standard error of an individual determination (root mean square), and

$100\,\sigma_p/p$ = percentage variation.

[d] Value not included in statistical analysis.

[e] (a-b) Different operators.

TABLE III.—SUMMARY OF RESULTS OF COOPERATIVE TESTS ON THE PROPOSED ACID OXIDATION —MOLYBDIVANADO METHOD FOR PHOSPHORUS.

Laboratory	Sample 7-9786	Sample 7-9787	Sample 7-9788	Sample 7-9789	Sample 7-9790
A	0.0004 0.0004 0.0005	0.0034 0.0031 0.0029	0.0200 0.0191 0.0197	0.190 0.196 0.198	1.97 1.94 1.93
B		0.00136 0.00085^{b}	0.0209^{b} 0.0234^{b}	0.199 0.200	1.945 1.962
C	0.00037 0.00053 0.00032	0.00261 0.00248	0.0199 0.0196 0.0200	0.1978 0.1969 0.1985 0.2005	1.935 1.920 1.961
D	0.0005 0.0004 0.0002	0.00250 0.00203 0.00250	0.0200 0.0210 0.0200	0.205 0.200 0.200	1.91 1.85 1.80
E	Could not determine	0.0024 0.0023 0.0019	0.0196 0.0187 0.0187	0.198 0.193 0.193	1.85 1.84 1.81
F	0.0004 0.0004	0.0029 0.0029 0.0028 0.0019	0.0201 0.0198	0.202 0.198 0.197	1.96 1.96
G	0.000^{b} 0.000^{b}	0.0034 0.0025	0.0198 0.0194	0.188 0.189	1.91 1.92
H	0.00032 0.00032 0.00033 0.00013	0.0023 0.0024	0.0186 0.0184	0.190 0.192	1.85 1.89 1.87
I	0.00034 0.00038 0.00027	0.00271 0.00265	0.0182 0.0186 0.0199	0.200 0.198 0.195	1.94 1.93 1.97
J	Could not determine	0.0020 0.0046^{b} 0.0026	0.0202 0.0202 0.0211	0.196 0.202 0.201	2.01 1.95 2.03
K	0.00005 0.00014 0.00020	0.00241 0.00228 0.00234	0.0204 0.0202 0.0202	0.197 0.196 0.211	1.932 1.928 1.926
L	0.0003	0.0022 0.0023 0.0040^{b} 0.0022	0.0200 0.0198	0.200 0.199 0.205	2.06 2.06 2.00
Blended to	0.0003^{c}	0.0020	0.020	0.20	2.0
Summary:^{a}					
N	22	30	29	34	33
$\overline{P}$	0.000327	0.00248	0.0197	0.198	1.93
σ_p	0.000123	0.000436	0.000724	0.00478	0.0632
$100\,\sigma_p/\bar{p}$	37.6	17.6	3.68	2.4	3.27

The symbols used in this summary are defined as follows:

[a] N = number of individual determinations averaged,

$\overline{P}$ = arithmetic average,

σ_p = standard error of an individual determination (root mean square), and

$100\,\sigma_p/\bar{p}$ = percentage variation.

[b] Value not included in statistical analysis.

[c] ±0.0001. By centrifuge method. No phosphorus added.

APPENDIX IX

PROPOSED METHOD OF TEST FOR BROMINE NUMBER OF PETROLEUM DISTILLATES (COLOR INDICATOR METHOD)[1]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St. Philadelphia 3, Pa.

Scope

1. (*a*) This method is intended for the determination of the bromine number of petroleum distillates that are substantially free of material lighter than isobutane and that have 90 per cent distillation points under 620 F. The method is generally applicable to materials that fall within the following limits:

A.S.T.M. 90 per cent Distillation Point, deg. Fahr.	Bromide Number, max.
Under 400	100
400 to 620	40

(*b*) Because of the variable reactivity of olefins, the bromine number obtained on various petroleum distillates is not an absolute measure of the olefins present but rather a criterion of certain properties of the material tested. It is known that high bromine numbers are obtained with polymer gasolines and those containing highly branched olefins or diolefins. Also, samples containing anthracene-type aromatics or sulfur compounds react to a certain extent with bromine under the conditions of the test. Thus, when bromine numbers are converted to olefins, the values obtained may not be definite and may vary from case to case unless the composition of the material tested is well established.

Definition

2. *Bromine Number* is the number of grams of bromine consumed by 100 g. of the sample when reacted under given conditions.

Outline of Method

3. The sample, dissolved in carbon tetrachloride, is treated at room temperature with an excess of bromide - bromate solution in the presence of glacial acetic acid. The excess bromine is reduced with potassium iodide and the liberated iodine determined by titration with sodium thiosulfate solution.

Apparatus

4. *Iodine Number Flasks*, 500-ml., glass-stoppered, will be required.

Reagents

5. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications established by the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. References to water shall be understood to mean distilled water.

(*a*) *Carbon Tetrachloride*.—Make blank determinations on 5-ml. portions of each lot of carbon tetrachloride as described in Section 7 (*c*).

(*b*) *Acetic Acid, Glacial.*

(*c*) *Bromide - Bromate Solution* (*Standard 0.5 N*).—Dissolve 49.6 g. of KBr and 13.9 g. of $KBrO_3$ (or the equivalent 43.0 g. of NaBr and 12.6 g. of $NaBrO_3$) in water and dilute to 1 liter. To standardize, place 50 ml. of glacial acetic acid and 1 ml. of HCl (sp. gr. 1.18) in a 500-ml. iodine number flask. Chill the solution in an ice bath for approximately 10 min. and, with constant swirling of the flask, add from a 10-ml. calibrated buret 5 ± 0.01 ml. of bromide - bromate solution at the rate of 1 to 2 drops per second. Stopper the flask immediately, shake the contents, place it again in the ice bath, and add 5 ml. of KI solution in the lip of the flask. After 5 min., remove the flask from the ice bath and allow the KI solution to flow into the flask by slowly removing the stopper. Shake vigorously, add 100 ml. of water in such a manner as to rinse the stopper, lip, and walls of the flask, and titrate promptly with $Na_2S_2O_3$ solution. Near the end of the titration, add 1 ml. of starch indicator solution and titrate slowly to disappearance of the blue color. Calculate the normality of the bromide-bromate solution as follows:

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[1] This proposed method is under the jurisdiction of the A.S.T.M. Committee D-2 on Petroleum Products and Lubricants. Published as information, October, 1949.

$$\text{Normality of bromide - bromate solution} = \frac{\text{ml. of } Na_2S_2O_3 \times \text{normality of } Na_2S_2O_3}{5}$$

Repeat the standardization until duplicate determinations do not differ from the mean by more than plus or minus 0.002 *N*.

(*d*) *Potassium Iodide Solution* (*150 g. per l.*).

(*e*) *Sodium Thiosulfate Solution* (*Standard 0.1 N*).—Dissolve 25 g. of $Na_2S_2O_3 \cdot 5H_2O$ in water, add 0.01 g. of Na_2CO_3 to stabilize the solution, and mix thoroughly by shaking. Standardize by any accepted procedure that determines the normality with an error not greater than plus or minus 0.0002. Restandardize at intervals frequent enough to detect changes of 0.0005 in normality.

(*f*) *Starch Solution.*—Triturate 5 g. of arrowroot starch and 5 to 10 mg. of HgI_2 with 3 to 5 ml. of water. Add the suspension to 2 liters of boiling water and boil for 5 to 10 min. Allow to cool and decant the clear, supernatant liquid into glass-stoppered bottles.

Check Procedure

6. In case of doubt in applying the procedure to actual samples, the reagents and technique should be checked by means of determinations on freshly purified cyclohexene and diisobutene. Make the tests according to the procedure described in Section 7, using as a sample either 0.5 to 1 g. of freshly purified cyclohexene or diisobutene (see Table II) or 8 to 10 g. of 10 per cent by weight solutions of these materials in carbon tetrachloride. If the reagents and technique are correct, values within the following ranges should be obtained:

Standard	Bromine Number
Cyclohexene, purified (Notes 1 and 2)	191 to 199 (Note 3)
Cyclohexene, 10 per cent solution. . .	19 to 20
Diisobutene, purified (Notes 1 and 2)..	142 to 148 (Note 3)
Diisobutene, 10 per cent solution....	14 to 15

NOTE 1.—Purified samples of cyclohexene and diisobutene may be prepared from Eastman cyclohexene, No. 1043, and Eastman diisobutylene, No. 2125 by the following procedure:

Add 65 g. of activated silica gel (28 to 200 mesh)[2] to a column approximately 16 mm. in inside diameter, and 760 mm. in length, which has been tapered at the lower end and which contains a small plug of glass wool at the bottom. A 100-ml. buret, or any column that will give a height-to-diameter ratio of the silica gel of at least 30:1, will be suitable. Tap the column during the addition of the gel to permit uniform packing.

To the column add 30 ml. of the olefin to be purified. When the olefin disappears into the gel, fill the column with methanol. Discard the first 15 ml. of percolate and collect the next 10 ml., which is the purified olefin for test of the bromine number procedure. Determine and record the density and refractive index of the purified samples at 20 C. Discard the remaining percolate.

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[2] Silica gel satisfactory for this purpose can be obtained from the Davison Chemical Corp., Baltimore, Md.

Caution.—If distillation of these olefins is employed as a pre-purification step, at least 10 per cent residue should remain in the distillation flask to minimize the hazards from decomposition of any peroxides that may have been present.

NOTE 2.—The reference olefins yielding the above results are characterized by the properties shown in Table I.

NOTE 3.—The theoretical bromine numbers of cyclohexene and diisobutene are 194.8 and 142.3, respectively. Diisobutene typifies a reactive type olefin which undergoes bromine substitution easily and usually gives bromine number values 2 to 6 units higher than theoretical by the check procedure. This condition is recognized with disfavor but considered acceptable for most routine testing of material in this category.

The theoretical value of diisobutene may be more closely approached by rigid control of the time schedule and excess bromine concentration to the minima permitted by the detailed procedure. It is to be expected that the accuracy of the bromine number determination for the reactive type olefins will be improved as the check procedure with diisobutene approaches the theoretical value of 142.3.

TABLE I.—PHYSICAL PROPERTIES OF PURIFIED OLEFINS.

Compound	Boiling Point deg. Cent	Density at 20 C., g. per cu. cm.	Index of Refraction, *D* Line at 20 C.
Cyclohexene	82.5 to 83.5	0.8100	1.4465
Diisobutene	101 to 102.5	0.7175 ±0.0015	1.4112

Procedure

7. (*a*) Place 10 ml. of carbon tetrachloride in a 50-ml. volumetric flask and, by means of a pipet, introduce a quantity of sample as indicated in Table II (Note 4). Either obtain the weight of sample introduced by difference between the weight (to the nearest milligram) of the flask before and after addition of sample or, if the density is known accurately, calculate the weight from the measured volume. Fill the flask to the mark with carbon tetrachloride and mix well (Note 5). Pipet a 5-ml. aliquot of the solution into a 500-ml. iodine number flask containing 50 ml. of glacial acetic acid.

NOTE 4.—Frequently, the order of magnitude of the bromine number of a sample is unknown. In this case, a trial test is recommended using a 2 g. sample in order to obtain the approximate magnitude of the bromine number. This exploratory test is to be followed with another determination using the appropriate sample size as indicated in Table II.

NOTE 5.—The dilution of the sample may be made with glacial acetic acid in place of carbon tetrachloride if desired. If the dilution of the sample is made with glacial acetic acid, the 5-ml. aliquot should be added to an iodine number flask containing 45 ml. of glacial acetic acid and 5 ml. of of carbon tetrachloride.

(*b*) Shield the flask from exposure to direct sunlight and keep it at a temperature of 25 ± 5 C. Add bromide - bromate solution from a buret at a rate of 1 to 2 drops per second, swirling the flask constantly during the addition. Continue adding the reagent until the reaction mixture assumes a yellow color (Note 6) that remains for at least 5 sec. Add an additional 1 ml. of the reagent as quickly as possible, stopper the flask, and continue swirling immediately for 40 ± 5 sec. At the end of this period, place 5 ml. of KI solution in the lip of the flask and lift the stopper, allowing the solution to flow slowly into the flask. Replace the stopper, shake vigorously, add 100 ml. of water, and shake again for 1 min. Titrate promptly with $Na_2S_2O_3$ solution. Near the end of the titration, add 1 ml. of starch indicator solution and titrate slowly to disappearance of the blue color. Discard the test if the back-titration is less than 5 ml. or

TABLE II.—SAMPLE SIZE.

Bromine Number	Sample Size, g.
0 to 10	20 to 16
Over 10 to 20	10 to 8
Over 20 to 50	5 to 4
Over 50 to 100	2 to 1.5
Over 100	1 to 0.5

greater than 10 ml. of $Na_2S_2O_3$ solution (Note 7).

NOTE 6.—The yellow color produced should be equivalent to that obtained by adding 0.5 ml. of bromide - bromate solution to 50 ml. of glacial acetic acid and 5 ml. of carbon tetrachloride in a similar flask.

NOTE 7.—In certain cases, notably high-boiling samples, it is impossible to meet the requirements of a 5 to 10-ml. $Na_2S_2O_3$ back-titration; in such cases, the results are indeterminate.

(*c*) *Blanks.*—Make duplicate blank determinations on each lot of reagents by repeating the entire procedure but using 5 ml. of carbon tetrachloride in place of the sample (Note 8).

NOTE 8.—In routine work, no correction need be applied so long as the blank does not exceed 0.02 milliequivalent of bromine. For work of highest accuracy, a correction should be applied if the blank exceeds 0.01 milliequivalent. The correction shall be made by subtracting from the term ($VN - vn$) in Section 8 the milliequivalents of bromine consumed by the volume of carbon tetrachloride actually present in the 5-ml. aliquot of sample solution used in the analysis. This volume may vary from 2.5 to 4.9 ml., depending upon the quantity of sample used.

Calculation

8. Calculate the bromine number of the sample as follows:

$$\text{Bromine number} = \frac{(VN - vn) \times 7.99}{W}$$

where:

V = milliliters of bromide - bromate solution added to the sample,
N = normality of the bromide - bromate solution,
v = milliliters of $Na_2S_2O_3$ solution used for the back-titration,
n = normality of the $Na_2S_2O_3$ solution, and
W = grams of sample represented by the aliquot used.

Precision

9. Results should not differ from the mean by more than the following amounts:

A.S.T.M. 90 per cent Distillation Point, deg. Fahr.	Range of Bromine Number	**Repeatability,** One Operator and Apparatus	**Reproducibility,** Different Operators and Apparatus
Under 400	0 to 20	0.5	1
	Over 20 to 50	1	2
	Over 50 to 100	2.5	5
400 to 620	0 to 10	2	4
	Over 10 to 20	3	6

APPENDIX X

PROPOSED METHOD OF TEST FOR BROMINE NUMBER OF PETROLEUM DISTILLATES (ELECTROMETRIC METHOD)[1]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Scope

1. (*a*) This method is intended for the determination of the bromine number of petroleum fractions that are substantially free of material lighter than isobutane and that have 90 per cent distillation points between 350 and 620 F.

(*b*) The bromine number obtained is frequently interpreted as a measure of olefin content. Such values obtained by this means may not be reliable due to variable reactivity of olefins and to the reactivity of many sulfur, nitrogen, and oxygen-containing compounds. Therefore this interpretation is limited to materials that are substantially free of these elements, and that are known to contain no olefins which absorb bromine slowly or incompletely.

Definition

2. *Bromine Number* is the number of grams of bromine consumed by 100 g. of the sample when reacted under given conditions.

Outline of Method

3. The sample is dissolved in a specified solvent and titrated with bromide-bromate solution at 0 to 5 C. The end point is indicated by a dead-stop electrometric titration apparatus.

Apparatus

4. The apparatus shall consist of the following:

(*a*) *Dead-Stop Electrometric Titration Apparatus.*—The method as written is based on the use of the electric eye titrimeter described in the Supplement.[2] Any other dead-stop apparatus may be used with approximately 0.5 v. across the two platinum electrodes and capable of measuring the potential across the electrodes with a sensitivity of plus or minus 50 mv.

(*b*) *Titration Cell.*—A 150-ml. glass vessel jacketed to permit cooling with ice water The pair of platinum wire electrodes shall be mounted to extend well below the liquid level. Stirring shall be by means of a mechanical stirrer and shall be rapid but not so vigorous that air bubbles are drawn down to the electrodes.

Reagents

5. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications established by the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.

(*a*) *Titration Solvent.*—Prepare 1 liter of titration solvent by mixing the following volumes of materials: 714 ml. of glacial acetic acid, 134 ml. of carbon tetrachloride, 116 ml. of methanol, 18 ml. of H_2SO_4 (1:5), and 18 ml. of a methanol solution of $HgCl_2$ (100 g. per l.).

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[1] This proposed method is under the jurisdiction of the A.S.T.M. Committee D-2 on Petroleum Products and Lubricants. Published as information, October, 1949.

[2] An electric eye titrimeter conforming to these requirements may be obtained from the Berkeley Scientific Co., Richmond, Calif. A Beckman Model H-2 pH meter, with adapter No. 700-1, has also been found satisfactory for this purpose.

(*b*) *Bromide - Bromate Solution* (*Standard 0.500 N*).—Dissolve 51.0 g. of KBr and 13.92 g. of $KBrO_3$ in distilled water and dilute to 1 liter in a volumetric flask.

Check Procedure

6. In case of doubt, or when new reagent or solvent is used, the procedure should be checked by means of determinations on freshly purified diisobutene or cyclohexene. Make the test according to the procedure described in Section 7. The values obtained should be 142.3 ± 5 for diisobutene and 194.6 ± 5 for cyclohexene. The values 142.3 and 194.6 are the theoretical values for diisobutene and cyclohexene, respectively.

TABLE I.—PHYSICAL PROPERTIES OF PURIFIED OLEFINS.

Compound	Boiling Point, deg. Cent.	Density at 20 C., g. per cu. cm.	Index of Refraction, *D* line at 20 C.
Diisobutene......	101 to 102.5	0.7175 ±0.0015	1.4112
Cyclohexene......	82.5 to 83.5	0.8100	1.4465

NOTE.—Eastman diisobutene, No. 2125, and Eastman cyclohexene, No. 1043, have been found satisfactory when purified by the following procedure:

Add 65 g. of silica gel (28 to 200 mesh)[3] to a column approximately 16 mm. in inside diameter and 760 mm. in length, tapered at the lower end, and containing a glass wool plug. Tap the column while adding the silica gel to obtain uniform packing. Any column giving a height-to-diameter ratio of the silica gel of at least 30:1 is suitable. The column should be jacketed to permit circulation of coolant.

Add 30 ml. of the olefin to the ice-water cooled column. When the olefin disappears into the gel, fill the column with methanol. Discard the first 15 ml. of percolate and collect the next 10 ml., which is the purified olefin. Discard the remainder. Olefins purified in this manner have exhibited the properties shown in Table I.

Procedure

7. (*a*) Introduce 110 ± 10 ml. of titration solvent into the titration vessel, start stirring, and cool to 0 to 5 C. Add the quantity of sample shown in Table II. Samples that exhibit poor solubility should first be dissolved in chloroform, then transferred to the titration vessel. Do not use more than 10 ml. of chloroform.

(*b*) Adjust the "eye" of the electrometric titration apparatus to a very nearly closed position. Add the bromide-bromate solution in small increments from a buret, noting the action of the "eye," which when open shows the presence of unabsorbed bromine. The end point is indicated when two drops of reagent cause the "eye" to remain open for at least 30 sec.

TABLE II.—SAMPLE SIZE.

Bromine Number	Approximate Sample Size, g.
Over 100..	0.2
25 to 100..	0.5
1 to 25..	2
Under 1..	5

(*c*) Make a blank titration on each lot of titration solvent. Less than 0.1 ml. of bromide - bromate solution should be required.

Calculation

8. Calculate the bromine number as follows:

$$\text{Bromine number} = \frac{(A - B)N \times 8}{W}$$

where:

A = milliliters of bromide - bromate solution used for titration of the sample,

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[3] Silica gel satisfactory for this purpose can be obtained from the Davison Chemical Corp., Baltimore, Md.

B = milliliters of bromide-bromate solution used for titration of the blank,

N = normality of the bromide-bromate solution, and

W = grams of sample used.

Precision

9. Results should not differ from the mean by more than the following amounts:

A.S.T.M. 90 per cent Distillation Point, deg. Fahr.	Range of Bromine Number	**Repeatability,** One Operator and Apparatus	**Reproducibility,** Different Operators and Apparatus
Under 400	0 to 20	0.7	1.5
	Over 20 to 50	2	4
	Over 50 to 100	2.5	5
400 to 620	0 to 10	1	2
	Over 10 to 20	2	4

SUPPLEMENT

APPARATUS

Apparatus:

A1. The electrometric titrimeter should be constructed according to the wiring diagram shown in Fig. 1. Connection to the platinum wire electrodes is made at the points labeled 1 and 4.

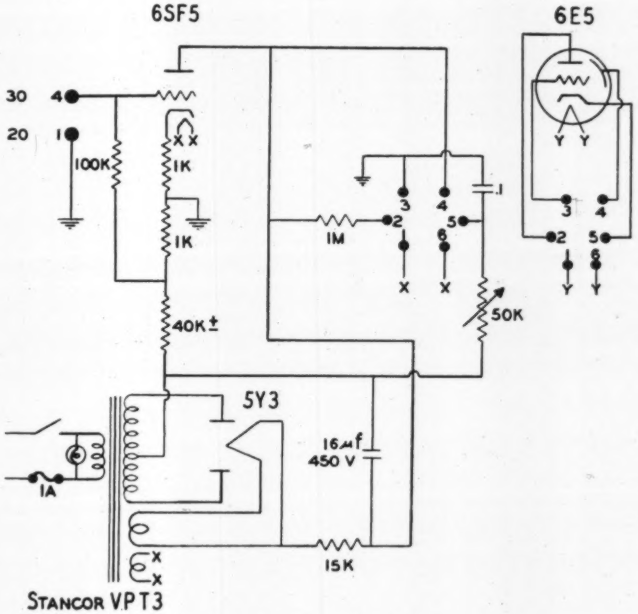
6SF5
6E5
30
20
4
1
100K
XX
1K
1K
40K±
1M
3
4
2
5
6
X
X
.1
50K
Y Y
3
4
2
5
6
Y
Y
5Y3
16μf
450 V
1A
15K
X
X
STANCOR VPT3

FIG. 1.—Electrometric Titrimeter.

REPORT OF COMMITTEE D-3
ON
GASEOUS FUELS*

Meetings of both Committee D-3 on Gaseous Fuels and its Advisory Committee were held in Atlantic City, N. J., on October 3, 1948. Three subcommittees also met on the same day.

A number of changes in personnel of Committee D-3 were made during the year. At present, the committee consists of 32 members of whom 8 are classified as consumers, 12 as producers, and 12 as general interest members.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Collection of Gaseous Samples (E. O. Mattocks, chairman).—A revised procedure for sampling of natural gas was distributed to the subcommittee members for review and approval. A proposed procedure for the sampling of manufactured gas was recently completed and distributed for consideration.

A procedure for sampling liquefied petroleum gas previously developed by this subcommittee was reviewed by the National Bureau of Standards. An additional section has been prepared as the result of this review and is being included in the procedure for committee action.

It is hoped to have methods for the sampling of natural and liquefied petroleum gases in readiness for action by Committee D-3 in the near future.

Subcommittee II on Measurement of Gaseous Samples (H. S. Bean, chairman) has reviewed several drafts of a proposed tentative method for measuring gaseous fuel samples. At its October 3 meeting the subcommittee again revised this method which has since been sent to subcommittee members with a letter ballot on its submission to Committee D-3.[1]

Subcommittee IV on Determination of Specific Gravity and Density of Gaseous Fuels (E. F. Schmidt, chairman).—The third draft of proposed tentative methods for determination of specific gravity of gaseous fuels has been presented to the subcommittee. Several members have already indicated their approval of this draft while others suggested minor changes. Necessary modifications have been completed and the revised draft is in readiness for presentation to the subcommittee for letter ballot approval. When this is obtained, the draft will be submitted to Committee D-3 and after approval to the Administrative Committee on Standards for acceptance as tentative.[1]

Subcommittee V on Determination of Special Constituents of Gaseous Fuels (E. H. Smoker, chairman).—While no meeting of this subcommittee was held during the past year, the members have endeavored by correspondence to complete a proposed tentative method for the determination of total sulfur in gas. This method will be considered further at the June meeting of the subcommittee.

Subcommittee VII on Complete Analysis of Chemical Composition of Gaseous Fuels (Martin Shepherd, chairman) completed a cooperative analysis of a standard sample of carburetted water gas by the mass spectrometer during the past year. Proposed tentative methods now in preparation include the following:

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] See Editorial Note, p. 387.

1. Analysis of fuel gases of the carburetted water gas type by volumetric chemical methods,
2. Analysis of fuel gases of the carburetted water gas type by the mass spectrometer,
3. Analysis of fuel gases of the natural gas type by volumetric chemical methods, and
4. Analysis of fuel gases of the natural gas type by the mass spectrometer.

Materials and facilities are being assembled for the preparation of another A.S.T.M. standard sample for cooperative analysis by the two methods, volumetric chemical and mass spectrometry.

This report has been submitted to letter ballot of the committee which consists of 32 members; 27 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

A. W. GAUGER,
Chairman.

K. R. KNAPP,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-3 presented to the Society through the Administrative Committee on Standards the following recommendations:

New Tentative Methods for:

Measurement of Gaseous Fuel Samples (D 1071 - 49 T),
Determination of Specific Gravity of Gaseous Fuels (D 1070 - 49 T).

These recommendations were accepted by the Standards Committee on September 22, 1949, and the new tentative methods appear in the 1949 Book of A.S.T.M. Standards, Part 3.

REPORT OF COMMITTEE D-4
ON
ROAD AND PAVING MATERIALS*

Committee D-4 on Road and Paving Materials has held three meetings during the past year: in Detroit, Mich., on June 23, 1948; in St. Louis, Mo., on October 28, 1948; and in Chicago, Ill., on March 4, 1949.

In the death of Lester Kirschbraun on September 6, 1947, the committee lost one of its former active and loyal members. Mr. Kirschbraun had served also as a member of Committee D-8 on Bituminous Waterproofing and Roofing Materials, and Committee D-1 on Paint, Varnish, Lacquer, and Related Materials. A memorial resolution was prepared jointly by the three committees and a copy sent to his family and to the Society.

In 1948, the committee lost a valuable, respected and loved member by the death of Joseph E. Boyd. Mr. Boyd also served as a member of Committee C-9 on Concrete and Concrete Aggregates. In appreciation of his services, the committee adopted a memorial resolution, a copy of which was sent to his family and to the Society.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1948 Annual Meeting, Committee D-4 presented to the Society, through the Administrative Committee on Standards, recommendations for publication of the following:

Tentative Specifications for:

Preformed Expansion Joint Filler for Concrete (Bituminous Type) (D 994 – 48 T), and

Bituminous Paving Plant Requirements (D 995 – 48 T).

Tentative Revision of Standard Definitions of:

Terms Relating to Materials for Roads and Pavements (D 8 – 46).

The tentative specifications were accepted by the Administrative Committee on Standards on September 29, 1948, and appear in the 1948 Supplement to Book of A.S.T.M. Standards, Part II. The tentative revision of Standard Definitions D 8 was accepted by the Standards Committee on January 3, 1949, and is being recommended for adoption as standard as given later in this report.

NEW TENTATIVE

Committee D-4 joins with Committee C-9 in recommending that a proposed Tentative Method of Test for Soft Particles in Coarse Aggregates, as appended to the report of Committee C-9,[1] be accepted for publication.

REVISIONS OF TENTATIVES

Tentative Methods of Sampling Bituminous Materials (**D 140 – 48 T**).[2]—Committee D-4 recommends a revision of these methods by changing the minimum weight of the sample from "50 lb." to "2 lb." in line 8 of Section 14, subject to approval of Committee D-8.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27 - July 1, 1949.

[1] This method was accepted as tentative by the Society and appears in the 1949 Book of A.S.T.M. Standards, Part 3.

[2] 1948 Supplement to Book of A.S.T.M. Standards, Part II.

Tentative Specifications for Hot-Mixed, Hot-Laid Asphaltic Concrete for Base and Surface Courses (**D 947 – 48 T**).[2]—Committee D-4 recommends that these specifications be revised as follows:

Table I.—Make the following changes in this table:

Add "8" to the heading of the last column.

Size No. 57.—Change per cent finer than 1 in. from "90 to 100" to "95 to 100."

Size No. 78.—Change per cent finer than No. 8 from "0 to 5" to "0 to 10" and insert "0 to 5" finer than No. 16.

Size No. 8.—Insert "0 to 5" finer than No. 16.

Section 7 (*d*).—Delete the last two sentences as they are a repetition of the last two sentences of Section 5.

Tentative Specifications for Asphaltic Mixtures for Sheet Asphalt Pavements (**D 978 – 48 T**).[2]—The committee recommends that Table I of these specifications be revised by changing the requirement for Size No. 57, 1 in. sieve, from "90 to 100" to "95 to 100."

Tentative Methods of Sampling Bituminous Paving Mixtures (**D 979 – 48 T**).[2]—Committee D-4 recommends that these methods be revised as follows:

Section 4 (*a*).—Change line 5 to read as follows by the addition of the italicized words and number and the omission of the words and number in brackets: "the pile at two [quarter] points *180* [90] deg."

Section 4 (*c*).—Change the first sentence to read as follows by the addition of the italicized words and sentence and the omission of the words in brackets:

> Samples from a railroad car shall be taken from at least six points, approximately 12 in. below the surface, so distributed over the car [as to represent, proportionately, visible variations in the mixture.] *that they lie at the midpoints of sections representing one-sixth of the superficial area of the car, formed by a median line running lengthwise of the car and two cross lines dividing the length of the car into equal thirds. In case a greater number of samples are required to make up the composite, they shall be taken at points spaced according to a mutually satisfactory regular geometric pattern.*

Section 6 (*a*).—Insert "*the physical properties of the mixture and*" after the word "determining" in the third line.

Tentative Specifications for Bituminous Paving Plant Requirements (**D 995 – 48 T**).[2]—The committee recommends the following revisions in these specifications:

Title.—Change the word "Paving" to "Mixing."

Section 2 (*d*).—Add the following sentence to the end of this paragraph: "If the dryer is not equipped to heat, dry, and cool the aggregate in one operation for cold mixes, the plant shall have sufficient storage bins equipped with cooling devices to accomplish the specific result."

Section 2 (*e*).—In the fifth line, change the word "full" to "production."

Section 2 (*g*).—In the sixth line, change the word "sensitive" to "accurate."

Section 3 (*b*).—Change to read as follows by the addition of the italicized words and the omission of the words in brackets:

> (*b*) *Aggregate Scales.*—Scales for any weigh box or hopper may be either of the beam or springless dial type, and shall be of [a] standard make and design, [sensitive] *accurate* to 0.5 per cent of the [maximum] *indicated* load [that may be required.] *and sensitive to one-half the minimum graduation, which shall not be greater than 10 lb. All scales shall be equipped with a tare beam, and beam-type scales shall be equipped with a separate beam for each size of aggregate to be weighed in the batch.* When a beam-type scale is used, provision shall be made for indicating to the operator that the required load [in the weighing hopper] is being approached. [; the] *This* device shall

indicate at least the last 200 lb. of load. *When springless dial scales are used, the end of the pointer shall be set close to the face of the dial and shall be of a type which will be free from excessive parallax. The scale shall be provided with an adjustable pointer for marking the weight of each material to be weighed into the batch.* [The scale shall also be equipped with a tare beam or adjustable counter-balance for balancing the hopper. A minimum of ten 50-lb. standard test weights shall be available for checking accuracy.] *Not less than ten standard 50-lb. test weights shall be provided for the purpose of testing and calibrating the scales. For each scale a suitable cradle or platform shall be provided for applying the test loads. The test weights shall be kept clean and located for convenient calibration of the scale.*

Section 3 (c).—Substitute the following sentence for the third, fourth, and fifth sentences: "Scales for the bitumen bucket shall conform to the requirements for aggregate scales, as specified in Paragraph (*b*), except that the minimum graduation shall not be greater than $2\frac{1}{2}$ lb. and the device for indicating the approaching load shall indicate the last 20 lb. of load."

Tentative Revisions of Standards

Standard Method of Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (**C 131 – 47**).[3]—Committee D-4 joins with Committee C-9 in recommending that the tentative revision of this method submitted in June, 1947, be withdrawn and replaced by a new tentative revision as given in the Report of Committee C-9.[1] The present standard method provides only for testing coarse aggregates up to $1\frac{1}{2}$ in. in size. Because of the use of larger sizes, particularly in highway construction and for railroad ballast, the need for broadening the scope of test has been felt for some time and a tentative revision providing for testing sizes up to 3 in. was recommended for publication in June, 1947. The latter tentative revision is replaced by the present recommended tentative revision. Cooperative laboratory investigations were carried out with the view of making the same conditions apply to coarser sizes as now exists with the present four gradings, that is, make it feasible to fix the same specification limits for all sizes to indicate a given quality. These studies indicate that a modification of the tentative revisions submitted in 1947 will go much further toward the goal of providing approximately the same percentage of loss in the larger sizes as in the smaller sizes for the same quality of material.

Standard Definitions of Terms Relating to Materials for Roads and Pavements (**D 8 – 46**).[4]—The committee recommends publication of a tentative revision of the following two terms in these definitions:

Tars.—Change to read as follows:

> *Tar.*—A bituminous material, viscous or fluid, resulting from the destructive distillation of organic matter such as coal, petroleum, shale, peat, and vegetable matter. The word "tar" should always be preceded by the name of the matter from which it is produced.

Viscosity.—Change to read as follows:

> *Viscosity.*—The internal friction in a bituminous material which tends to restrict flow.

Revisions of Standards, Immediate Adoption

Committee D-4 recommends that the following revisions of standards be immediately incorporated in the standards, and accordingly requests the necessary nine-tenths affirmative vote at the Annual Meeting in order that the recommendations may be referred to letter ballot of the Society.

Standard Definitions of Terms Relating to Materials for Roads and Pavements (**D 8 – 46**).[4]—Delete the definitions of the following terms: dehydrated tars, chert, granite, granitoid, and soil. There does not appear to be any particular need for a definition of dehydrated tars. It is not apparent why it is necessary to define any of the varieties of rock, nor why definitions of chert, granite, and granitoid should be included in standard definitions while definitions of other rocks used in road construction are excluded. The definition of soil is not adequate, and it is felt that this definition should be the responsibility of Committee D-18 on Soils for Engineering Purposes.

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[3] 1947 Supplement to Book of A.S.T.M. Standards, Part II.

[4] 1946 Book of A.S.T.M. Standards, Part II.

Standard Method of Test for Amount of Material Finer Than No. 200 Sieve in Aggregates (**C 117 – 48**).[2]—In the Table of Section 3, change the heading "Nominal Diameter of Largest Particle," to "Nominal Maximum Sieve Size," and under this heading change "$\frac{1}{4}$" to "No. 4." These changes bring this standard in accord with other A.S.T.M. standards relative to designation of sieve sizes. A similar recommendation for revision of this standard is being made by Committee C-9 on Concrete and Concrete Aggregates, which has joint jurisdiction with Committee D-4.

Standard Method of Float Test for Bituminous Materials (**D 139 – 27**):[4]

Section 2 (*c*).—Insert the following as the second sentence of this paragraph: "This adjustment of the total weight of the assembly is for the purpose only of calibrating the depth of immersion in the testing bath."

Section 2 (*e*).—Change to read as follows:

> (*e*) *Testing Bath.*—A water bath at least 185 mm. in internal diameter and containing water at least 185 mm. in depth. The height of the container above the surface of the water shall be at least 100 mm.

Add the following as a new Paragraph (*f*) to this section:

> (*f*) ***Water Bath at 5 C.***—**A water bath of suitable dimensions maintained at 5.0 C. ± 1.0 C., which may be accomplished by means of melting ice.**

Section 3.—Change the heading of this section from "Preparation of Sample" to "Procedure" and delete the heading "Procedure" of the present Section 4.

Section 3 (*b*).—Insert the word "easy" between the words "for" and "pouring" in the fourth line of this paragraph.

Sections 3 (*c*) *and* (*d*).—Change to read as follows by the addition of italicized words and numbers and the omission of those in brackets:

(*c*) *Asphalt and Asphalt Products.*—Asphalt and asphalt products shall be cooled to room temperature *for 15 to 60 min., then* placed *for 5 min. in the water bath at 5 C.*, [in water maintained at 5 C. for 5 min.] after which the surplus material shall be [removed] *trimmed flush with the top of the collar* by means of a spatula, or steel knife, which has been slightly heated. The collar and plate shall then be placed in [a tin cup containing ice water maintained at 5 ± 1 C.,] *the water bath at 5 C.*, and left in this bath for [at least] *not less than* 15 min. *nor more than 30 min.*

(*d*) *Tar Products.*—Tar products shall be immediately immersed [in ice water maintained at 5 C.] for 5 min. *in the water bath at 5 C.*, after which the surplus material shall be [removed] *trimmed flush with the top of the collar* by means of a spatula, or steel knife, which has been slightly heated. The collar and plate shall then be placed in [a tin cup containing ice water maintained at 5 ± 1 C.,] *the water bath at 5 C.*, and left in this bath for [at least] *not less than* 15 min. *nor more than 30 min.*

Section 4 (*a*) *and* (*b*).—Reletter as Paragraphs (*e*) and (*f*) of Section 3 and change to read as follows by the addition of the italicized words and numbers and the omission of those in brackets:

"(*e*) [The bath shall be filled with water and] the water *in the testing bath shall be* heated to the temperature at which the test is to be made. This temperature shall be accurately maintained *without stirring*, and shall at no time throughout the test be allowed to vary more than 0.5 C. from the temperature specified. *The temperature shall be determined by immersing the thermometer with the bottom of the bulb at a depth of 40 ± 2 mm. below the water surface.*

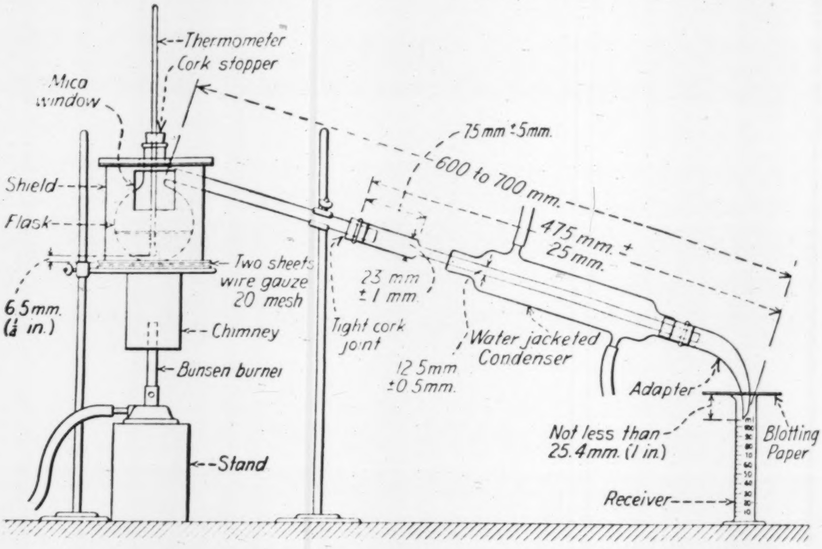
Thermometer
Cork stopper
Mica window
Shield
Flask
Two sheets wire gauze 20 mesh
6.5mm. (¼ in.)
Chimney
Bunsen burner
Stand
75 mm ±5mm.
600 to 700 mm.
475 mm. ± 25 mm.
23 mm ± 1 mm.
Tight cork joint
12.5mm ±0.5mm.
Water jacketed Condenser
Adapter
Not less than 25.4mm. (1 in.)
Blotting Paper
Receiver

FIG. 1. Distillation Apparatus Assembly.

"(*f*) After the material to be tested has been kept in the [ice water] *water bath at 5 C.* for not less than 15 min. nor more than 30 min., the collar with its contents shall be removed from the plate and screwed into the aluminum float, and *then the assembly shall be completely* immersed [in water at 5 C.] for 1 min. *in the water bath at 5 C.* [Any] *The* water shall then be removed from the inside of the float and the [latter] *assembly* immediately floated [in the warm] *on the testing* bath. *Lateral drift of the assembly shall be permitted, but no spinning motion shall be intentionally imparted thereto.* As the plug of material becomes warm and fluid, it is forced upward and out of the collar until the water gains entrance into the saucer and causes it to sink."

Section 4 (*c*).—Reletter as Paragraph (*g*) of Section 3.

New Section.—Add a new Section 4 on Precautions, designating the note in the present Section 4 as Paragraph (*a*) and adding the following as Paragraph (*b*):

(*b*) Owing to possible danger to health if mercury is handled carelessly, the following rules should be observed at all times:

(*1*) Store the mercury in a closed jug in a cool place.

(*2*) Strictly avoid spilling any mercury.

(*3*) Remove mercury vapors by working under a suitable hood with good ventilation.

(*4*) Keep amalgamated brass plates and other apparatus at not above normal room temperature.

The recommended revisions in this standard are primarily improvements in phraseology designed to clarify details of procedure. Essential requirements of the present standard are not modified and the revisions are essentially editorial in nature. An additional requirement covering position of the thermometer in the testing bath is proposed, however, since the present standard is silent in this important respect, and a precautionary section on the use of mercury, similar to those submitted for other methods involving amalgamated apparatus, is recommended.

Standard Method of Test for Distillation of Cut-Back Asphaltic Products (**D 402 – 48**):[2]

Section 1.—Add the following note to the end of this section:

NOTE.—The test results on the residue may be affected by non-asphaltic materials present in the asphalt.

Section 7 (a).—Change the last sentence to read as follows by the addition of the italicized words and sentence: "Assemble the apparatus and apply heat so that the first drop *from the end of the flask tubulature* comes over in 5 to 15 min. *Either water or oil shall be considered in recording the first drop of material distilled.*

Figure 3.—Substitute the accompanying Fig. 1 of the distillation apparatus assembly showing the corrected upper water connection at the top of the jacketed condenser and the lower connection at the bottom of the jacket.

Section 7 (d).—In the second sentence change "5 sec." to "10 sec."

Standard Specifications for Standard Sizes of Coarse Aggregate for Highway Construction (**D 448 – 47**).[3]—The following revision of these specifications is recommended in order that the requirements for standard sizes of coarse aggregate will be in accordance with those recommended by the U. S. Department of Commerce in its Simplified Practice Recommendation R163-48, approved June 30, 1948, and issued by the National Bureau of Standards.

Table I.—Make the following changes: Add an additional heading for a sieve size, No. 50 (297-micron), between the headings for No. 16 (1190-micron) and No. 100 (149-micron).

Make the following changes in requirements:

Size No. 3.—Change per cent finer than 2 in. from "90 to 100" to "95 to 100."

New Size.—After size No. 467, add a new size No. 5 with a nominal size of 1 to $\frac{1}{2}$ in., per cent finer than $1\frac{1}{2}$ in., 100; 1 in., 90 to 100; $\frac{3}{4}$ in., 20 to 55; $\frac{1}{2}$ in., 0 to 10; $\frac{3}{8}$ in., 0 to 5.

Size No. 5.—Change size number to "56."

Size No. 57.—Change per cent finer than 1 in. from "90 to 100" to "95 to 100."

Size No. 68.—Change per cent finer than No. 8 from "0 to 5" to "0 to 10," and insert "0 to 5" finer than No. 16.

Size No. 78.—Change per cent finer than No. 8 from "0 to 5" to "0 to 10," and insert "0 to 5" finer than No. 16.

Size No. 8.—Insert "0 to 5" finer than No. 16.

Size No. 89.—Insert "0 to 5" finer than No. 50.

Size No. 9.—Insert "0 to 5" finer than No. 50.

Standard Specifications for Crushed Stone, Crushed Slag, and Gravel for Bituminous Concrete Base and Surface Courses of Pavements (**D 692 – 47**).[3]—The following revisions are recommended in order that these specifications will be in accord with the revised requirements and the reason thereof of Specifications D 448 as given above. The addition of Size No. 7 as a coarse aggregate for use in fine-graded bituminous concrete surface course mixtures has been recommended to bring these specifications into accord with Tentative Specifications D 947.

Section 5 (a).—Change size "No. 5" to "No. 56" wherever it appears in this paragraph. Insert size "No. 7" as a size specified for use in fine-graded bituminous concrete surface course in this paragraph.

Note 2.—Change the combinations of sizes to read as follows:

Coarse Aggregate Size	Seal-Coat Aggregate Size
56 or 57	78
67	8
7, 78, or 8	9

Table I.—Make the following changes: Add an additional heading for a sieve size, No. 50 (297-micron), after the heading for No. 16 (1190-micron).

Make the same changes for size Nos. 3, 5, 57, 78, 8, and 9, as given above for Table I of Standard Specifications D 448.

New Size.—Between size Nos. 67 and 78, add the following requirements for a new size No. 7 to read as follows: "nominal size, $\frac{1}{2}$ in. to No. 4; $\frac{3}{4}$ in., 100; $\frac{1}{2}$in., 90 to 100; $\frac{3}{8}$ in., 40 to 70; No. 4, 0 to 15; No. 8, 0 to 5."

Standard Specifications for Crushed Stone and Crushed Slag for Bituminous Macadam Base and Surface Courses of Pavements (**D 693 - 44**).[4]—The committee considers that the new size No. 5, as well as the former size No. 5, is suitable for use as choke aggregate when size No. 1 or size No. 2 is used as penetration course aggregate, and accordingly recommends that this size be incorporated in these specifications. The other revisions are recommended in order that the specifications will be in accord with the revised requirements of Specifications D 448 given above and with those recommended by the U. S. Department of Commerce in its Simplified Practice Recommendation R163-48.

Section 5.—Insert size No. 56 below size No. 5 as an additional size number for use as choke aggregate.

In the table of the note to this section, insert "56" in the suggested sizes of choke aggregate for use with viscous binders and with No. 1 or No. 2 sizes of penetration course aggregate.

Table I.—Make the following changes: Add an additional heading for sieve size, No. 50 (297-micron).

Make the same changes for size Nos. 3, 5, 78, 8, and 9, as given above for Table I of Standard Specifications D 448.

New Size.—After size No. 3, add a new size "5" with the same requirements as given above for the new size No. 5 in Standard Specifications D 448.

Standard Specifications for Crushed Stone, Crushed Slag, and Gravel for Water-Bound Macadam Base and Surface Courses of Pavements (**D 694 - 44**).[4]—The committee recommends the following revision to bring these specifications in accord with the requirements recommended by the U. S. Department of Commerce in its Simplified Practice Recommendation R163-48.

Table I.—Change the requirement for size No. 3, 2 in. sieve, from "90 to 100" to "95 to 100."

ADOPTION OF TENTATIVES AS STANDARD

Tentative Specifications for Emulsified Asphalt (**D 977 - 48 T**).[2]—Committee D-4 recommends that these specifications be approved for reference to letter ballot of the Society for adoption as standard without revision. These specifications are in effect a consolidation of five existing standard specifications without change of essential requirements and, when adopted, will replace those standards.

Tentative Method of Test for Moisture-Density Relations of Soils (**D 698 - 42 T**).[4]—The committee joins with Committee D-18 in recommending that this method be approved for reference to letter ballot of the Society for adoption as standard.

Tentative Method of Test for Penetration of Bituminous Materials (**D 5 - 47 T**).[3]—The committee also recommends that this method be approved for reference to letter ballot of the Society for adoption as standard, with the following revisions:

Section 4.—Change the sixth sentence to read as follows by the addition of the italicized words and numbers and the omission of the numbers in brackets: "The container and its contents shall be loosely covered as a protection against dust and be allowed to cool in an atmosphere at a temperature *not higher than 29.5 C. (85 F.) and* not lower than [24 C. (75.2 F.)] *21 C. (70 F.)* for not less than $1\frac{1}{2}$ nor more than 2 hr."

Section 5 (b).—Change the second sentence to read as follows by the addition of the italicized words and the omission of those in brackets: "After each test the sample and transfer dish shall be returned to the water bath while the needle is being carefully wiped toward its point *first* with a clean [dry] cloth *moistened with carbon tetrachloride* to remove all adhering bitumen, *then with a clean, dry cloth.*"

Tentative Method of Test for Hot Extraction of Asphaltic Materials and Recovery of Bitumen by the Modified Abson Procedure (**D 762 – 47 T**).[3]—The committee recommends that this method be approved for reference to letter ballot of the Society for adoption as standard, with the following revision:

Section 5.—Add the following as a new Paragraph (*a*), relettering the present paragraphs accordingly: "5 (*a*) The following steps must be completed within 8 hr."

ADOPTION OF TENTATIVE REVISIONS AS STANDARD

Standard Methods of Testing Emulsified Asphalts (**D 244 – 42**).[4]—Committee D-4 joins with Committee D-8 in recommending that the tentative revision of these methods, submitted in June, 1947, be approved for reference to letter ballot of the Society for adoption as standard. The tentative revision comprises the addition of sections covering a method for determination of residue by evaporation as an alternate to the method by distillation.

Standard Specifications for Preformed Expansion Joint Fillers for Concrete (Nonextruding and Resilient Types) (**D 544 – 48**) and *Standard Methods of Testing Preformed Expansion Joint Fillers for Concrete (Nonextruding and Resilient Types)* (**D 545 – 48**).[2]—The committee also recommends that the tentative revisions of these two standards submitted in June, 1948, be approved for reference to letter ballot of the Society for adoption as standard.

Standard Definitions of Terms Relating to Materials for Roads and Pavements (**D 8 – 46**).[4]—The committee further recommends that the tentative revisions of these definitions submitted in November, 1948, be approved for reference to letter ballot of the Society for adoption as standard. These revisions comprise improvements in definitions of the following terms: Bituminous Material, Bituminous Emulsion, Cut-Back Products, Flux, Asphalt, Asphalt Rock (Rock Asphalt), and Water-Gas Tar; and withdrawal of definitions for the following terms: Petroleum, Topped Petroleum, Dead Oils, and Matrix.

WITHDRAWAL OF STANDARDS

In view of the recommendations for adoption as standard of Tentative Method D 5 – 47 T and Tentative Specifications D 977 – 48 T, referred to earlier in this report, Commitee D-4 recommends that the following standards be withdrawn:

Standard Method of Test for:

Penetration of Bituminous Materials (D 5 – 25)

Standard Specifications for:

Medium-Setting Emulsified Asphalt (for Coarse Aggregate Plant Mixes) (D 397 – 39),
Medium-Setting Emulsified Asphalt (for Retread and Coarse Aggregate Mixes) (D 398 – 39),

Medium-Setting Emulsified Asphalt (Heavy Premix-Summer Grade) (D 399 - 39),
Quick-Setting Emulsified Asphalt (for Penetration and Surface Treatment) (D 401 - 40), and
Slow-Setting Emulsified Asphalt (for Fine Aggregate Mixes) (D 631 - 46).

The requirements of Standard Specifications for Sand for Sheet Asphalt and Bituminous Concrete Pavements (D 162 - 29) are inconsistent with the requirements of Tentative Specifications D 947 and D 978, and the committee is preparing a revision of the standard specifications for sand. It is accordingly recommended that Standard Specifications D 162 be withdrawn.

Editorial Changes in Standards

The committee recommends that the following three standards be editorially changed, as indicated, by the addition of a Section on Precautions.

Standard Method of Test for Softening Point of Bituminous Materials (Ring-and-Ball Method) **(D 36 - 26)**:[4]

Section 10.—Add a new Paragraph (*c*) to read the same as that given for Paragraph (*b*) of the new Section 4 of Standard Method D 139.

Standard Method of Test for Softening Point of Tar Products (Cube-in-Water Method) **(D 61 - 38)**:[4]

New Section 7.—Add a new Section 7 on Precautions by transfering Notes 1 and 2 of Section 4 (*c*) as Paragraphs (*a*) and (*b*), respectively, and add a new Paragraph (*c*) to read the same as that given for Paragraph (*b*) of the new Section 4 of Standard Method D 139.

Standard Method of Test for Ductility of Bituminous Materials **(D 113 - 44)**:[4]

New Section 5.—Add a new Section 5 on Precautions which shall read the same as that given for Paragraph (*b*) of the new Section 4 of Standard Method D 139.

Reaffirmation of Standards

The committee recommends that the following seven standards which have been published for six years or longer without revision be reaffirmed:

Method of Test for Abrasion of Rock by Use of the Deval Machine (D 2 - 33)
Method of Test for Toughness of Rock (D 3 - 18)
Method of Test for Distillation of Tar Products Suitable for Road Treatment (D 20 - 30)
Method of Test for Softening Point of Bituminous Materials (Ring-and-Ball Method) (D 36 - 26)
Method of Test for Softening Point of Tar Products (Cube-in-Water Method) (D 61 - 38)
Method of Test for Specific Gravity of Road Oils Road Tars, Asphalt Cements, and Soft Tar Pitches (D 70 - 27)
Method of Test for Specific Gravity of Asphalts and Tar Pitches Sufficiently Solid to be Handled in Fragments (D 71 - 27).

Standards Continued Without Revision

Committee D-4 recommends that the following standards be continued as standard, without revision. All of these standards have been reviewed by the subcommittees responsible for their development and found to be satisfactorily in accord with present practice.

Standard Specifications for:

Materials for Cement Grout Filler for Brick and Stone Block Pavements (D 57 - 20),
Materials for Sand-Cement Bed for Brick and Block Pavements (D 58 - 37),
Granite Block for Pavements (D 59 - 39),
Coal-Tar Pitch for Stone Block Filler (D 112 - 30),
Recut Granite Block for Pavements (D 131 - 39),
Granite Block for Durax Pavements (D 132 - 39),
Asphalt Filler for Brick Pavements (D 241 - 43),
Mineral Filler for Sheet Asphalt and Bituminous Concrete Pavements (D 242 - 39),
Asphalt Plank (D 517 - 40), and
Sodium Chloride (D 632 - 43).

Standard Methods of Test for:

Determination of Bitumen (D 4 - 42),
Proportion of Bitumen Soluble in Carbon Tetrachloride (D 165 - 42),
Residue of Specified Penetration (D 243 - 36), and
Sieve Analysis of Mineral Filler (D 546 - 41).

Recommended Practice for:

Bituminous Paving Plant Inspection (D 290 – 39).

Committee D-4 joins with Committee C-9 in recommending that the Standard Method of Test for Specific Gravity and Absorption of Coarse Aggregate (C 127 – 42) and the Standard Method of Test for Specific Gravity and Absorption of Fine Aggregate (C 128 – 42) be continued as standard, without revision.

TENTATIVES CONTINUED WITHOUT REVISION

The subcommittees of Committee D-4 and the joint subcommittee of Committees D-4 and D-18 have reviewed existing tentative specifications and methods of test which have been published by the Society for two years or more without revision, and Committee D-4 recommends that the following be continued as tentative without revision:

Tentative Specifications for:

Materials for Stabilized Base Course (D 556 – 40 T) and Materials for Stabilized Surface Course (D 557 – 40 T). An effort is being made by the joint subcommittee of Committees D-4 and D-18 and by a committee of the American Association of State Highway Officials to combine these two specifications and to present a more direct and simplified specification for suitable materials.

Asphalt Cement for Use in Pavement Construction (D 946 – 47 T). A subcommittee of Committee D-4 is engaged in a study of additional requirements involving control of uniformity and properties of asphalt cements.

Tentative Methods of Test for:

Loss on Heating of Oil and Asphaltic Compounds (D 6 – 39 T). This method is believed not to have the precision desired, and a subcommittee has work in progress for the development of improved apparatus and procedure. The present tentative method has been in extensive use for many years, however, and should be retained until a better method can be adopted.

Soil-Bituminous Mixtures (D 915 – 47 T). Exploratory tests involving some modifications in testing temperatures are being conducted to determine whether the method may be improved as a means of differentiating between soils of varying characteristics.

Shear Strength of Flexible Road Surfaces, Subgrades, and Fills by the Burggraf Shear Apparatus (D 916 – 47 T). An effort is being made to improve this method of test and to insure more direct and uniform results as a result of observations made in extensive use of this method on field projects by a committee of the Highway Research Board.

The recommendations appearing in this report have been approved by letter ballot of the committee, the results of which will be reported at the Annual Meeting.[5]

ACTIVITIES OF SUBCOMMITTEES

In 1947 the Society accepted for publication a tentative revision of the Standard Method of Test for Distillation of Cut-Back Asphaltic Products (D 402 – 36), which was revised and adopted in 1948 as a standard method of test. Important revisions of the previous standard method include requirements for dimensions and capacity of the distillation flask, the rate of distillation, and the size of container used to receive the distillation residue. Experience with the former standard method had shown that the rates of distillation specified were not adaptable to all commercial materials, and that difficulties with foaming were a common experience. The revised method adopted in 1948 has been shown to eliminate practically all of these difficulties and to give results substantially the same as the former method, making revision of specification requirements unnecessary. The results of comparative tests on a series of cut-back asphaltic products made by laboratories cooperating in the development of the revised method are shown in Table I.

Subcommittees B-2 on Physical Tests for Compressed Bituminous Mixtures (L. F. Rader, chairman) *and B-25 on Effect of*

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[5] The letter ballot vote on these recommendations was favorable. the results of the vote are on record at A.S.T.M. Headquarters.

TABLE I.—RESULTS OF COMPARATIVE DISTILLATION TESTS OF CUT-BACK ASPHALTIC PRODUCTS.

	Lab. A	Lab. B	Lab. C	Lab. D	Lab. E	Lab. F	Lab. G	Average
Product MC-3 Tested by A.S.T.M. Method D 402 - 36[a]								
Distillation; per cent								
off at 500 F	8.0	8.0	7.5	7 25	7.5	7.5	....	7.63
off at 600 F	16 0	15.5	15.75	16.0	16.0	16.25	....	15.9
off at 680 F	21.0	20.2	20.0	20.0	20.0	20.5	....	20.29
Distillation Residue: Penetration at 77 F (100 g., 5 sec.)	169	162	147	160	140	160	....	156
Product MC-3 Tested by A.S.T.M. Method D 402 - 48[b]								
Distillation; per cent								
off at 500 F	7.0	7.5	7.0	6.0	6.0	7 0	6 5	6.7
off at 600 F	15.5	15.5	15.5	16.0	15.0	16.0	15.75	15.61
off at 680 F	20.5	20.6	19.75	20.5	19.5	20.25	20.5	20.23
Distillation Residue: Penetration at 77 F (100 g., 5 sec.)	177	158	148	176[c]	161	139	167	158
Product MC-5 Tested by A.S.T.M. Method D 402 - 36[a]								
Distillation; per cent								
off at 500 F	1.5	1.0	1.0	0.75	1.25	0.75	....	1.04
off at 600 F	7.5	7.5	7.5	7.5	8 0	8.0	....	7.66
off at 680 F	12.0	11.0	11.25	11.0	12.0	11.75	....	11.5
Distillation Residue: Penetration at 77 F (100 g., 5 sec.)	151	149	129	153	132	146	....	143
Product MC-5 Tested by A.S.T.M. Method D 402 - 48[b]								
Distillation; per cent								
off at 500 F	0.5	1.0	1.0	1.0	0.75	1.0	0.0	0.875
off at 600 F	7.5	7.6	7.5	7.5	6.75	7.25	7.0	7.3
off at 680 F	12.5	11.0	11.0	11.5	10.5	11.0	11.75	11.32
Distillation Residue: Penetration at 77 F (100 g., 5 sec.)	155	140	132	155[c]	144	130	144	141
Product RC-2 Tested by A.S.T.M. Method D 402 - 36[a]								
Distillation; per cent								
off at 500 F	22.0	20.6	22.0	21.5	20.75	21.5	....	21.39
off at 600 F	24.0	24 0	24.25	24.0	23.25	24.0	....	24.25
off at 680 F	26.0	25.5	26.25	25.25	25.0	26.0	....	25.67
Distillation Residue: Penetration at 77 F (100 g., 5 sec.)	104	97	95	88	92	106	....	97
Product RC-2 Tested by A.S.T.M. Method D 402 - 48[b]								
Distillation; per cent								
off at 500 F	21.0	20.5	21.5	20.25	21 0	20.25	21.0	20.79
off at 600 F	23.5	23.3	24.0	23 0	24.0	22.75	24 0	23.51
off at 680 F	26.0	25.4	26.0	25.0	26.0	24.75	26.0	25.59
Distillation Residue: Penetration at 77 F (100 g., 5 sec.)	112	97	90	90[c]	105	93	102	97
Product RC-5 Tested by A.S.T.M. Method D 402 - 36[a]								
Distillation; per cent								
off at 500 F	8.5	7.7	8.0	6.5	8.0	8.5	....	7.87
off at 600 F	10.5	9.5	10.0	8.5	9.75	10.5	....	9.79
off at 680 F	12.0	10.7	11.0	9.5	11.25	12.0	....	11.07
Distillation Residue: Penetration at 77 F (100 g., 5 sec.)	106	97	95	87	97	103	....	98
Product RC-5 Tested by A.S.T.M. Method D 402 - 48[b]								
Distillation; per cent								
off at 500 F	7.5	8.0	7.5	7.5	6.5	7.75	7.0	7.39
off at 600 F	10.0	10 0	9.5	9.0	9 0	9.5	9.5	9.5
off at 680 F	12.0	11.0	11.0	10.7	10.5	11.25	11.0	11.07
Distillation Residue: Penetration at 77 F (100 g., 5 sec.)	107	100	94	108[c]	92	101	102	99

[a] These results were obtained using a 200-ml sample with a 300-ml. flask and a 6-oz. container.

[b] These results were obtained using a 200 ml sample with a 500-ml. flask and an 8-oz container.

[c] This test was made using the 6-oz. container; accordingly this value is not included in calculating average.

Water on Compressed Bituminous Mixtures (C. A. Carpenter, chairman) have prepared proposed methods for determining the resistance to plastic flow of fine-aggregate bituminous mixtures, the compressive strength of compacted bituminous mixtures, and the effect of water on such mixtures. It is expected that tentative methods of test will be submitted to the Society during the coming year.[6]

Subcommittee B-6 on Extraction and Recovery of Constituents from Bituminous Mixtures (R. R. Thurston, chairman) has comparative tests in progress in connection with the development of a method for the determination of the bitumen content of paving mixtures.

Subcommittee B-7 on Viscosity and Float Test (J. N. Roche, chairman) plans to develop a tentative method for the determination of Engler specific viscosity and to conduct cooperative tests to study various details of the float test procedure for bituminous road materials.

Subcommittee B-12 on Structural Properties of Mineral Aggregates (Stanton Walker, chairman) has prepared a proposed method for the determination of soft particles in coarse aggregates referred to earlier in this report and is actively studying an abrasion test for sand.

Subcommittee B-21 on Solubility Tests (E. H. Porter, chairman) has conducted a series of comparative tests in connection with preparation of an improved procedure for determining the percentage of bitumen by the present standard method.

Subcommittee C-5 on Portland-Cement Concrete for Pavements and Bases (A. A. Anderson, chairman) is preparing to formulate a proposed specification for portland-cement concrete for highway pavements and bases.

Subcommittee C-10 on Plant-Mix Bituminous Surfaces and Bases (Fred Hubbard, chairman) is actively engaged in considering suggested improvements in the present tentative specifications for plant-mixed bituminous mixtures and in preparing specifications for nonbituminous materials utilized in these mixtures which are not adequately covered by present A.S.T.M. specifications.

Subcommittee C-13 on Bituminous Paving Plant Operations (I. H. Boggs, chairman) plans to review the Recommended Practice for Bituminous Paving Plant Inspection (D 290 – 39) and to recommend changes in this standard for the purpose of incorporating the best practice in modern mixing plant operations.

Subcommittee D-3 on Expansion Joint Materials (W. C. Ricketts, chairman) is preparing additional specifications for expansion joint materials and methods for their examination and expects to recommend a number of tentatives during the coming year.

RESEARCH ACTIVITIES

In addition to research involved in the standardization and improvement of testing methods, the subcommittees of Committee D-4 are engaged in the study of various problems upon which considerable research is necessary before essential information can be utilized in more significant and reliable methods of testing or control of materials. The field of the more important investigations may be indicated by listing the following subjects:

1. Development of a more reproducible and significant method for the determination of asphalt content of asphaltic road materials.
2. Study of existing laboratory methods for the physical testing of compressed bituminous mixtures and the development or standardization of adequate procedures.
3. Development and standardization of methods for determining structural properties of

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[6] See Editorial Note, p. 400.

mineral aggregates as related to highway performance.

4. Development of significant methods for determining the setting or curing properties of bituminous highway materials.

5. Development of an improved and reproducible procedure for determination of the volatile matter in bituminous road materials.

6. Study of accelerated tests for durability of bituminous materials, as related to performance and service.

7. Development and standardization of methods for determining the effect of moisture on the performance of compacted bituminous road mixtures.

8. Development and standardization of methods for determining the effect of water on bituminous coatings applied to mineral aggregates as a means of controlling characteristics of aggregates and bituminous binders.

9. Study of methods for determining the specific gravity of coarse and fine aggregates, particularly those of absorptive character, and the significance of various determinations as related to their utilization in specifications for and control of aggregates and highway mixtures.

10. Development and standardization of laboratory and field methods for the design and control of soils, soil mixtures, and treated soil mixtures as utilized for the construction of highway bases and surfacings.

This report has been submitted to letter ballot of the committee, which consists of 143 members; 101 members returned their ballots, of whom 98 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

F. H. BAUMANN,
Chairman.

B. A. ANDERTON,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-11 presented to the Society through the Administrative Committee on Standards the following recommendations:

New Tentative Specifications for:

Concrete Joint Sealers, Hot-Poured Type (D 1072 - 49 T), and
Fine Aggregate for Sheet Asphalt and Bituminous Concrete Pavements (D 1073 - 49 T).

New Tentative Methods of:

Test for Compressive Strength of Bituminous Mixtures (D1074 - 49 T), and
Test for Effect of Water on Cohesion of Compacted Bituminous Mixtures (D 1075 - 49 T).

Tentative Revision of Standard Method of:

Test for Determination of Bitumen (D 4 - 42).

Tentative Revision of Standard Recommended Practice for:

Bituminous Paving Plant Inspection (D 290 - 39).

These recommendations were accepted by the Standards Committee on September 22, 1949, and the new tentatives and tentative revisions appear in the 1949 Book of A.S.T.M. Standards, Part 3.

REPORT OF COMMITTEE D-5
ON
COAL AND COKE*

Committee D-5 on Coal and Coke held meetings in Detroit, Mich., on June 24, 1948, and in Chicago, Ill., on March 1, 1949.

The Advisory Subcommittee held a meeting in Detroit, Mich., on June 24, 1948, and in Chicago, Ill., on March 1, 1949. It was agreed that the committee should cooperate in the international standardization of methods for sampling and analysis of coal for foreign trade. This work is a continuation of a project formerly started by the International Standards Association and now under the jurisdiction of Technical Committee 27 on Solid Mineral Fuels of the International Standards Organization. The United Kingdom through the British Standards Institution will serve as the secretariat of the project.

During the year three members were added to the committee and two members resigned, resulting in the present membership of 59, of whom 16 are classified as producers, 20 as consumers, and 23 as general interest members.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the Tentative Method of Drop Shatter Test for Coal (**D 440 – 48 T**), revised as appended hereto,[1] be approved for reference to letter ballot of the Society for adoption as standard.

REAFFIRMATION OF STANDARDS

The committee recommends reaffirmation of the following 15 standards[2] which have been published for six years or longer without revision and which are considered to be in accord with present practice:

Standard Specifications for:

Gas and Coking Coals (D 166 – 24),
Classification of Coals by Rank (D 388 – 38),
Classification of Coals by Grade (D 389 – 37).

Standard Method of Test for:

Volume of Cell Space of Lump Coke (D 167 – 24),
Cubic Foot Weight of Crushed Bituminous Coal (D 291 – 29),
Cubic Foot Weight of Coke (D 292 – 29),
Sieve Analysis of Coke (D 293 – 29),
Tumbler Test for Coke (D 294 – 29),
Size of Anthracite (D 310 – 34),
Sieve Analysis of Crushed Bituminous Coal (D 311 – 30),
Sampling Coke for Analysis (D 346 – 35),
Screen Analysis of Coal (D 410 – 38),
Index of Dustiness of Coal and Coke (D 547 – 41).

Standard Definitions of:

Terms Relating to Coal and Coke (D 121 – 30), and
Commercial Varieties of Bituminous and Subbituminous Coals (D 493 – 39).

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following methods, which have been published as tentative for two years or longer without revision, be continued as tentative because revisions are under consideration or in prospect:

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] This revised method was adopted as standard by the Society and appears in the 1949 Book of A.S.T.M. Standards, Part 5.

[2] 1946 Book of A.S.T.M. Standards, Part III-A.

Tentative Methods of Test for:

Grindability of Coal by the Ball-Mill Method (D 408 – 37 T),[2] and

Grindability of Coal by the Hardgrove-Machine Method (D 409 – 37 T).[2]

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Methods of Testing (W. A. Selvig, chairman).—A Special Section on Revision of Ultimate Analysis Methods, under the chairmanship of O. W. Rees, has been active this past year in accumulating data and conducting experimental work with a view of revising the methods for determination of carbon, hydrogen, and nitrogen as given in the Standard Methods of Laboratory Sampling and Analysis of Coal and Coke (D 271 – 48). This special section held a meeting in Chicago, Ill., on February 28, 1949, and made plans to prepare a revision of the methods for carbon and hydrogen for circulation for criticism. Another meeting of the special section is to be held in Pittsburgh in May. Laboratories of the following institutions are cooperating in this work: Battelle Memorial Institute, Columbus, Ohio; Canadian Bureau of Mines, Ottawa, Canada; Eastern Gas and Fuel Associates, Pittsburgh, Pa.; Illinois State Geological Survey, Urbana, Ill.; Institute of Gas Technology, Chicago, Ill.; School of Mineral Industries, Pennsylvania State College, State College, Pa.; and U. S. Bureau of Mines, Pittsburgh, Pa.

Subcommittee XI on Coal Friability (R. E. Gilmore, chairman) revised the Tentative Method of Drop Shatter Test for Coal (D 440 – 48 T) which is now being recommended for adoption as standard as revised. This revision eliminates the former provision that a standard size of 3 by 2-in. coal be used for comparing friability of different coals and this elimination required considerable changes in the text of the method. Experimental data have shown the unreliability of using a standard size of 3 by 2-in. as a criterion of judging relative friability of different coals.

Subcommittee XV on Plasticity and Swelling of Coal (C. C. Russell, chairman) at a meeting held in Chicago, Ill., on February 28, 1949, reported results of cooperative tests by different laboratories using the Gieseler plastometer method on standard samples of two widely different grades of pitch. These tests showed variations sufficiently large to show the need of further standardization of the instrument design. When this is done, cooperative tests will be made on new samples of pitch as a further check on reproducibility of test results.

As the free-swelling index test has been widely adopted both in this country and abroad, the subcommittee has agreed that the present Standard Method of Test for Free-Swelling Index of Coal (D 720 – 46) should be revised by adopting the term "zero button" to designate coals which do not form a coherent mass and that provisions should be made for estimating the swelling indices of coals which do not give buttons that match with the standard profiles. An appropriate scheme for the latter has been published by the U. S. Bureau of Mines,[4] and is under consideration by the subcommittee. A revision will probably be presented next year.

Subcommittee XVI on Ignitibility of Coal and Coke (R. A. Sherman, chairman) held a meeting on February 28, 1949, in

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[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

[4] W. A. Selvig and W. H. Ode, "An Investigation of a Laboratory Test for Determination of the Free-Swelling Index of Coal," U. S. Bureau of Mines *Report of Investigations No. 4238* (1948).

Chicago, Ill., to discuss a laboratory method of test it has had under consideration for some time for testing reactivity or ignitibility of coal. It has been difficult to correlate the results of the test method with the behavior of coal in regular combustion equipment; however, rather good correlation has been reported between the test method results and the storage characteristics of coal. The subcommittee plans to write up the method of test in standard form for publication for information so it would be available to anyone interested in starting work on the reactivity or ignitibility of solid fuels.

Subcommittee XX on Sampling and Fineness Test of Pulverized Coal (J. B. Romer, chairman) at a meeting held on March 1, 1949, in Chicago, Ill., announced plans of enlarging the personnel of the subcommittee by the addition of members representing some of the large public utilities burning pulverized coal. Experimental work is continuing on the problem of collecting representative samples of pulverized coal from streams of coal and air inside pipes between coal pulverizers and furnaces, and on procedures best adapted for making fineness tests in the laboratory. This investigation will lead to a major revision of the present Method of Sampling and Fineness Test of Powdered Coal (D 197 – 30).

This report has been submitted to letter ballot of the committee, which consists of 59 members; 54 members returned their ballots, of whom 53 have voted affirmatively and 1 negatively.

Respectfully submitted on behalf of the committee,

W. A. SELVIG,
Chairman.

C. H. SAWYER,
Secretary.

REPORT OF COMMITTEE D-6
ON
PAPER AND PAPER PRODUCTS*

Committee D-6 on Paper and Paper Products held two meetings during the year: on June 23, 1948, at Detroit, Mich., and on February 25, 1949, at New York, N. Y.

The Advisory Committee held two meetings during the year: on October 29, 1948, and on February 25, 1949, both at New York, N. Y.

Cooperative relations are being continued between Committee D-6 and other A.S.T.M. committees, as well as with other standardizing bodies.

At the present time, Committee D-6 consists of 86 members, of whom 70 are voting members; 27 are classified as producers, 26 as consumers, 27 as general interest, and 6 as consulting members.

NEW TENTATIVES

The committee recommends that the following four new methods, prepared by Subcommittees I and IV, be accepted for publication as tentative, as appended hereto:[1]

Tentative Methods of Test for:
Creasing Paper for Permeability Tests,
Fiber Analysis of Paper and Paperboard,
Ply Separation of Combined Container Board, and
Scuff Resistance of Paperboard.

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following five tentative methods be approved without change for reference to letter ballot of the Society for adoption as standard:

Tentative Methods of Test for:[2]
Bleeding Resistance of Asphalted Paper at Elevated Temperature (D 917 – 47 T)
Blocking Resistance of Paper and Paperboard (D 918 – 47 T),
Copper Number of Paper and Paperboard (D 919 – 47 T),
Crease Retention of Wrapping Paper (D 920 – 47 T), and
Titanium Dioxide in Paper (D 921 – 47 T).

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends for immediate adoption the following revisions in the Standard Method of Conditioning Paperboard, Fiberboard and Paperboard Containers for Testing (D 641 – 43) and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society:

Section 4. Add the following as a new Paragraph (*b*), relettering the subsequent paragraphs accordingly:

> (*b*) Specimens which are prepared for test by sealing or other assembly making use of aqueous adhesives shall be preconditioned after such operations to dissipate the moisture so added.

REAFFIRMATION OF STANDARDS

The committee recommends the reaffirmation of the following eleven standards which have stood for six years or more without revision and are still considered to be in accord with present practice:

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] These methods were accepted as tentative by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 4.

[2] 1947 Supplement to Book of A.S.T.M. Standards, Part III-B.

Standard Methods of Test for:

Bulking Thickness of Paper (D 527 - 41),
Machine Direction of Paper (D 528 - 41),
Water-Soluble Acidity or Alkalinity of Paper (D 548 - 41),
Sampling Paper and Paper Products (D 585 - 42),
Ash Content of Paper and Paper Products (D 586 - 42),
Casein in Paper (D 587 - 42),
Alpha-Beta- and Gamma-Cellulose in Paper (D 588 - 42),
Paraffin Content of Waxed Paper (D 590 - 42),
Starch in Paper (D 591 - 42),
Folding Endurance of Paper (D 643 - 43), and
Thickness of Paper and Paper Products (D 645 - 43).

TENTATIVE CONTINUED WITHOUT REVISION

An instrumentation study is currently being made in connection with the Tentative Method of Test for Puncture and Stiffness of Paperboard, Corrugated, and Solid Fiberboard (D 781 - 44 T). It is therefore recommended that this method be continued as tentative until this study is completed. The remaining tentative methods under the jurisdiction of Committee D-6, although requiring no revision, are also recommended for continuation as tentative.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Paper Testing Methods (M. S. Kantrowitz, chairman) held one meeting during the year. The work of the subcommittee was temporarily interrupted by the sudden death on January 18, 1949, of its previous chairman, C. G. Weber. The subcommittee has been active in developing new methods of test and has also continued its critical study of various methods of test of paper and paper products that have been adopted by other agencies, for example those of the Technical Association of the Pulp and Paper Industry. The subcommittee prepared two of the four new methods of test which are being recommended for publication as tentative, namely, Creasing Paper for Permeability Tests, and Fiber Analysis of Paper and Paperboard. The five tentative methods being recommended for adoption as standard and the eleven standards reapproved without revision are also under the jurisdiction of this subcommittee.

Methods on the following subjects are being given consideration by the subcommittee:

Erasability,
Stiffness,
Gloss,
Lint,
Chloride content,
Sulfate content, and
Expansivity.

In addition to the above subjects, studies are being made which may lead to proposed revisions in the Standard Methods of Test for Basis Weight of Paper and Paper Products (D 646 - 44) and Hydrogen Ion Concentration (pH) of Paper Extract (D 778 - 46) and the Tentative Method of Test for Organic Nitrogen in Paper and Paperboard (D 982 - 48 T).

Subcommittee II on Significance of Test Methods held no meetings during the year. C. C. Heritage resigned as chairman and L. S. Reid was appointed to succeed him in this office.

Subcommittee III on Specifications for Paper (P. S. Wehmer, chairman) held no meetings during the year. This subcommittee is currently developing specifications for filter paper for chemical analysis. It has also been studying various specifications for paper and paper products that have been adopted by other agencies, such as the Federal Specifications Board.

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[3] The letter ballot vote on these recommendations was favorable: the results of the vote are on record at A.S.T.M. Headquarters.

Subcommittee IV on Container Board (W. B. Lincoln, Jr., chairman) held two meetings during the year and is currently working on the following test procedures:

Ring crush test,
Static bending test,
Flat crush test,
Tensile strength test, and
Bursting strength test.

The subcommittee prepared two of the four new methods of test which are being recommended for publication as tentative, namely, Ply Separation of Combined Container Board, and Scuff Resistance of Paperboard. Standard Method D 641 for which revision is recommended for immediate adoption is also under the jurisdiction of this subcommittee.

The establishment of Subcommittee V on Research has been authorized and its organization will take place in the near future.

The Advisory Committee held two meetings during the year as previously noted. Various recommendations were made for the guidance of Committee D-6. Among the more important of these were recommendations for revision by Subcommittee II of the monograph on "Characteristics, Nomenclature and Significance of Tests" and for expansion of the work of Subcommittee III to include the development of specifications for papers used in multiwall bags and several additional papers of industrial importance.

This report has been submitted to letter ballot of the committee, which consists of 70 voting members; 42 members returned their ballots, of whom 37 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

W. R. WILLETS,
Chairman.

H. A. BIRDSALL,
Secretary.

REPORT OF COMMITTEE D-7

ON

WOOD[*]

Committee D-7 on Wood met at Chicago, Ill., on March 15, 1949, at the time of the Fiftieth Annual Meeting of the American Railway Engineering Association. A number of the subcommittees held meetings prior to the main committee meeting.

The membership of the committee now consists of 80 of whom 14 are consulting members. The recent significant increase reflects the broadening activities of the committee, as illustrated by the organization of Subcommittee VII on Wood Poles and Cross Arms and the increased interest in other phases of the work. Further enlargement is anticipated as Subcommittee XIII on Durability and Exposure is organized, and as other fields of work are activated.

NEW TENTATIVES

The committee recommends the publication as tentative of the following specifications and methods, as appended hereto:[1]

Tentative Specifications for:

Creosoted End Grain Wood Block Paving for Interior Use
Chromated Zinc Chloride
Tanalith

Tentative Methods of:

Chemical Analysis of Chromated Zinc Chloride
Chemical Analysis of Tanalith
Conducting Static Tests of Wood Poles
Test for Evaluating the Properties of Building Boards

Tentative Definitions of:

Terms Relating to Plywood and Veneer

REVISIONS OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends revisions for immediate adoption in the following standards and accordingly asks for a nine-tenths affirmative vote in order that these recommendations may be referred to letter ballot of the Society:

Standard Specifications for Creosote (**D 390 – 36**);[2]

Section 2.—Change footnote *a* to read as follows:

> [a] Samples of creosote taken from working tanks may show increases in matter insoluble in benzol and coke residue, due to treating operations. If neither the matter insoluble in benzol nor the coke residue exceeds the specification limit by more than 1 per cent of the sample, and if it can be shown that the original creosote was specified quality, the used creosote shall be regarded as conforming to the specification.

Standard Method of Test for Distillation of Creosote (**D 246 – 42**):[2]

Section 7 (b).—Change to read as follows:

(*b*) If the fraction up to 210 C. contains water, the amount of water shall be determined (Note). Correction to water-free basis according to the following formulas, shall be applied to each of the fractions to express percentage based on the weight of the water-free sample.

Fraction to 210 C.:

$$\text{Percentage (water-free basis)} = (\text{weight of fraction} - W) \times \frac{100}{100 - W}$$

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[*] Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] These specifications, methods, and definitions were accepted as tentative by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 4.

[2] 1946 Book of A.S.T.M. Standards, Part II.

Second and Subsequent Fraction Including Residue:

$$\text{Percentage (water-free basis)} = \text{weight of fraction} \times \frac{100}{100 - W}$$

where:

W = milliliters of water, expressed as grams, in fraction distilling to 210 C. (1 ml. of water = 1 g. (approx.))

NOTE.—The amount of water contained in this fraction may be determined by either of the following methods:

(*1*) Transfer fraction, after weighing, to a tube or cylinder graduated in $\frac{1}{10}$ ml. Rinse the receiver several times with benzol, adding rinsings to tube or cylinder containing fraction or,

(*2*) Fraction up to 210 C. may be collected in a tared 5 ml. graduated cylinder having a flared top. After weighing, add benzol which will result in a clear separation of the water and oily distillate.

Standard Methods of Test for Insoluble Matter in Creosote (**D 367 - 33**).[2]—The committee recommends revision of these methods as appended hereto.[3]

Standard Methods of Testing Small Clear Specimens of Timber (**D 143 - 48**):[4] The following changes will be effective in developing still further international agreement on methods of testing wood and are based on the recommendations of an international conference. These revisions broadly do not affect the basic procedures embodied in Methods D 143 for the several mechanical tests. An increase in the size of the toughness test specimen is recommended to bring it up to the minimum cross-section of 0.79 by 0.79 in. (2 by 2 cm.) recommended. Some of the changes are very minor and repetitive, as for example, the requirement that the moisture section shall be "approximately 1 in. in length" rather that "1 in. in length." Somewhat more accurate control of test conditions with respect to temperature is suggested because of the significant effect of this factor. In the shear-parallel-to-grain test, the speed of test has been increased from "0.015 in. per minute" to "0.024 in. per minute" to permit conducting this test more expeditiously. These are illustrative of the changes recommended.

Section 2 (*a*).—Omit from the first sentence "tension perpendicular to grain," and add the following as a new second sentence: "The tension perpendicular to grain test also included is optional."

Section 3.—Change to read as follows:

> 3. The material shall be from trees selected in the forest by one qualified to identify the species and to select the trees. Whenever practicable this should be a member of the timber mechanics staff of the laboratory concerned and where necessary herbarium samples including leaves, fruit, twigs, and bark shall be obtained to insure positive identification.

Section 4.—Change to read as follows:

> 4. For each species to be tested, at least five trees representative of the species shall be selected.

Section 5.—Change the first paragraph to read as follows:

> 5. The material of each species selected for test shall be representative of the merchantable bole of the tree. One method of selection which has been found satisfactory is as follows:

Section 13 (*b*).—Change to read as follows: "(*b*) Photographs of the standing trees selected should be taken where practicable."

Section 15.—Add the following to the last sentence and the subsequent sentence to the end of the paragraph: "and, when necessary, sprinkled regularly with water to prevent drying. As an alternative to piling on skids, the logs may be stored in water prior to testing."

Photographing, Sawing, and Final Marking.—Add the following as a note under this center heading.

> NOTE.—In sawing, marking and selecting test sticks, the aim should be to obtain specimens representative of the material collected. The procedure described herein is one that has been found satisfactory for most species.

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[3] These revised methods and specifications were accepted by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 4.

[4] 1947 Supplement to Book of A.S.T.M. Standards, Part II.

Section 19.—Add the following as a new Paragraph (*c*):

(*c*) The above procedure provides for end to end matching (end matching) of sticks to be tested air dry with those to be tested green, which is to be preferred when practicable. If, because of the nature of the material, end matching is not practicable, side matching may be used.

Section 22 (*c*).—Insert "approximately" before "1 in." in the first sentence. Change the last sentence to read as follows: "When conditioned to approximately 12 per cent moisture content, the material shall be surfaced on four sides to 2 by 2 in. in cross-section and tested."

Section 22 (*e*).—Change to read as follows:

(*e*) The seasoned sticks, whether kiln-dried or air-dried, preferably should be stored in a room having controlled temperature and humidity (at approximately 70 F. and 65 per cent relative humidity) before test to reduce the moisture gradient within the material, and to bring the material into equilibrium, which will be approximately 12 per cent moisture content for most species.

Section 24.—Change to read as follows:

24. In case the material from a given bolt should be insufficient to furnish all the test specimens hereinafter required (logs or bolts less than 24 in. in diameter), additional bolts may be selected. If additional material is not available the preferential order of mechanical tests to be used in selecting specimens shall be as follows: Static bending, compression parallel to grain, impact bending, toughness, compression perpendicular to grain, hardness, shear parallel to grain, cleavage, tension parallel to grain, and tension perpendicular to grain.

Section 30.—Change to read as follows:

30. Two toughness specimens shall be selected from the uninjured portion or end of each impact bending specimen or companion static bending specimen, making a total of 32 toughness specimens for each bolt. One from each group of two specimens from the same stick shall be tested with the load applied radially and the other tested with the load applied tangentially.

Control of Moisture Content and Temperature.—Add the following as a note under this center heading:

NOTE.—In recognition of the significant influence of temperature and humidity on the strength of wood it is highly desirable that these factors be controlled to ensure comparable test results.

Section 42.—Change to read as follows:

42. Independent of the effect on strength of the moisture content of the test specimens as influenced by temperature, is the significant effect of temperature itself on the mechanical properties. The specimens when tested shall be at a temperature of 70 F. or as near to 70 F. as practicable. The temperature at time of test shall in all instances be recorded as a specific part of the test record.

Section 45.—Change to read as follows:

45. Center loading and a span length of 28 in. shall be used. Both supporting knife-edges shall be provided with bearing plates and rollers of such thickness that the distance from the point of support to the central plane is not greater than the depth of the specimen (Fig. 6). The knife-edges shall be adjustable laterally to permit adjustment for slight twist or warp in the specimen. Alternately, the method of supporting the specimen in trunnion-type supports which are free to move in a horizontal direction may be employed.

Section 49.—In Paragraph (*a*), in the beginning of the second sentence, add "at least" before "one-third."

In Paragraph (*c*) of this section, add the following to the last sentence: "and also after abrupt changes in load."

In Paragraph (*d*) of this section, add "read and" before the word "shown."

Section 51.—Insert "approximately' before the length dimension "1 in."

Section 52.—Change to read as follows:

52. The compression-parallel-to-grain tests shall be made on nominal 2- by 2- by 8-in. specimens. The actual cross section dimensions, and the length shall be measured (Section 122).

Section 53.—Delete this section, renumbering the subsequent sections accordingly.

Figure 9.—Delete this figure.

Section 54.—Change to read as follows:

54. Special care shall be used in preparing the compression-parallel-to-grain test specimens to insure that the end grain surfaces will be parallel to each other and at right angles to the longitudinal axis. If deemed necessary, at least one platen of the testing machine shall be equipped with a spherical bearing to obtain uniform distribution of load over the ends of the specimen.

Section 55.—Delete this section on spherical bearing.

Section 56.—Change to read as follows:

56. The load shall be applied continuously throughout the test at a rate of motion of the movable crosshead of 0.003 in. per in. of specimen length per min. (Section 123).

Section 57 (a).—Change the first sentence to read as follows: "Load-compression curves shall be taken over a central gage length not exceeding 6 in. and preferably on all of the specimens." Delete the present third sentence.

Section 60.—Insert "approximately" before the length dimension "1 in."

Section 61.—Change the first sentence to read as follows: "When practicable, the number of rings per inch and the proportion of summer wood shall be measured over a representative inch of cross-section of the test specimen."

Section 68.—Change to read as follows:

68. Where desired, graphical drum records giving the deflection for each drop and the set, if any, should be made until first failure occurs. This record will also afford data from which the exact height of drop can be scaled for at least the first four falls.

Section 71.—Insert "approximately" before the length dimension "1 in."

Toughness.—Add the following as a note under this center heading.

NOTE.—A single blow impact test on a small specimen is recognized as a valuable and desirable test. Several types of machines such as the Toughness, Izod, and Amsler have been used, but insufficient information is available to decide whether one procedure is superior to another, or whether the results by the different methods can be directly correlated. If the Toughness machine is used, the following procedure has been found satisfactory. To aid in standardization and to facilitate comparisons the size of the toughness specimen has been made equal to that accepted internationally.

Section 72.—Change the first sentence to read as follows: "The toughness tests shall be made on 0.79 by 0.79 by 11-in. (2- by 2- by 28 cm.) specimens."

Section 73.—Change the first sentence to read as follows: "Center loading and a span length of 9.47 in. (24 cm.) shall be used."

Section 77.—Insert "approximately" before the length dimension "2 in."

Section 82 (a).—Add the following sentence to this paragraph: "Compression will be measured between the loading surfaces."

Section 83.—Insert "approximately" before the length dimension "1 in."

Section 85.—Change the second sentence to read as follows: "The load at which the "ball" has penetrated to one-half its diameter, as determined by an electrical circuit indicator or by the tightening of the collar against the specimen, shall be recorded."

Section 86.—Change the first sentence to read as follows: "Two penetrations shall be made on a tangential surface, two on a radial surface, and one on each end."

Section 88.—Insert "approximately" before the length dimension "1 in."

Shear Parallel to Grain.—Add the following as a note under this center heading:

NOTE.—The following describes one method of making the shear parallel-to-grain test that has been extensively used and found satisfactory.

Section 91.—Change to read as follows:

91. The load shall be applied continuously

throughout the test at a rate of motion of the movable crosshead of 0.024 in per min. (Section 123).

Tension Perpendicular to Grain.—Insert "Optional Test" under this center heading.

Tension Parallel to Grain.—Add the following as a note under this center heading:

NOTE.—One method of determining the tension-parallel-to-grain strength of wood is given in the following procedure.

Section 110.—Change Paragraphs (*a*), (*b*), (*d*), (*e*), and (*h*) to read as follows, leaving Paragraphs (*c*), (*f*), and (*g*) in their present form:

110. (*a*) Both specific gravity and shrinkage-in-volume determinations shall be obtained on the same specimen. These determinations should be made at approximately 12 per cent moisture content and in the oven-dry condition.

(*b*) A carbon impression of the end of the green specimen may be made on the back of the data card. In like manner, a carbon impression of the same end may be made after the specimen has been conditioned (Paragraphs (*d*) and (*e*)).

(*d*) The green specimens after immersion shall be open-piled and allowed to air-season under room conditions to a uniform moisture content of approximately 12 per cent. The specimens should then be weighed and the volume determined by the immersion method.

(*e*) The specimens used for specific gravity and shrinkage determinations at 12 per cent moisture content, or duplicate specimens on which green weight and volume measurements have been made prior to conditioning to approximately 12 per cent moisture content, shall then be open-piled in an oven and dried at 100 C. until constant weight is reached.

(*h*) Fig. 27 illustrates an apparatus used in determining the specific gravity and shrinkage in volume. The use of an automatic balance will facilitate increased rapidity and accuracy of measurements.

Section 114 (*a*).—Change to read as follows:

(a) The green specimens shall be open-piled and allowed to air-season under room conditions to a uniform moisture content of approximately 12 per cent.

Section 115.—Change to read as follows: "Measurements shall be made on the air-dry and on the oven-dry specimen."

Section 123.—In the first sentence, change "shall" to "should."

REVISION OF STANDARDS AND REVERSION TO TENTATIVE

The committee recommends that the following standards[2] be revised, as appended hereto,[3] and reverted to tentative:

Standard Specifications for:

Creosote-Coal-Tar Solution (D 391 - 36),
Zinc Chloride (D 432 - 39), and

Standard Methods of:

Chemical Analysis of Zinc Chloride (D 199 - 27).

STANDARDS CONTINUED WITHOUT REVISION

The committee recommends that the following 12 standards[2] which have stood for six years or longer without revision be continued as such without change:

Standard Specifications for:

Round Timber Piles (D 25 - 37),
Wooden Paving Blocks for Exposed Pavements (D 52 - 20).

Standard Methods of:

Sampling and Testing Creosote (D 38 - 33),
Test for Coke Residue of Creosote (D 168 - 30),
Static Tests of Timbers in Structural Sizes (D 198 - 27),
Volume and Specific Gravity Correction Tables for Creosote and Coal-Tar (D 347 - 33),
Test for Specific Gravity of Creosote (D 368 - 33),
Test for Specific Gravity, 38/15.5 C., of Creosote Fractions (D 369 - 33),
Test for Water in Creosote (D 370 - 33),
Test for Tar Acids in Creosote and Creosote-Coal-Tar Solutions (D 453 - 41).

Standard Definitions of:

Terms Relating to Timber (D 9 - 30), and
Terms Relating to Timber Preservatives (D 324 - 41).

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[5]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Specifications for Timber (L. J. Markwardt, chairman).—In accordance with the action taken at the 1948 meeting of Committee D-7, consideration was given to the withdrawal of the Standard Specifications for Structural Wood Joist and Planks, Beams and Stringers, and Posts and Timbers (D 245 - 37). Criticism of this standard was raised by the lumber industry because it was not in conformity with the grading rules of the various regional lumber associations and hence could not be used directly for purchase of structural material. While the specification requirements of Specification D 245 were in accord with accepted principles of structural grading and with American Lumber Standards, it did not contain a foreword calling attention to the fact that it was not recognized commercially, or a cross reference relating it to the accepted commercial specifications of the regional lumber associations.

The subcommittee voted to recommend the withdrawal of Standard D 245[6] as such, and replace it with a new one covering the broad principles of stress grading as set forth in U.S.D.A. *Miscellaneous Publication No. 185* and its two supplements, and by illustrating the principles by one or more grade examples.

Subcommittee II on Laminated Timber (F. J. Hanrahan, chairman).—A draft of a tentative method of test for determining the integrity of glue joints in laminated structural members for exterior service was prepared and reviewed by the subcommittee as its meeting on March 14. The method under consideration involves cyclic treatments consisting, while immersed in water, of a 2 hr. vacuum (20 to 25 in. of mercury), a 2 hr. air pressure (75 psi), both after repetition to be followed by drying in air for 88 hr. (80 to 85 F., 30 per cent relative humidity). By repeating this entire cyclic procedure twice, a 12-day test is provided as compared to the six-months period which was previously required. Further study will be given the proposed method during the year.

Subcommittee III on Plywood (J. A. Liska, chairman) prepared during the past year a list of standard definitions of terms relating to veneer and plywood. The definitions are in general agreement with accepted usage. Terms involving glues and gluing were not included since these are being covered by Committee D-14 on Adhesives.

Subcommittee IV on Wood Paving Blocks (W. H. O'Brien, chairman) restudied the Proposed Specifications for Creosoted End Grain Wood Block Flooring for Interior Use. The list of species was revised, and the specification was divided into two parts, Material and Installation. The question of broadening the specification to include preservatives other than creosote was considered, but it was agreed that other treatments should be covered in separate specifications. The specification approved by the subcommittee is recommended for acceptance as a new tentative, as given earlier in the report.

Subcommittee VI on Timber Preservatives (R. H. Bescher, chairman).—The activities of the subcommittee during the year included the review of existing standards and the preparation of specifications and methods of tests for two others of the recognized wood preservatives, namely, chromated zinc chloride and tanalith. The various actions recommended with respect to continuation without change and revision of present standards, and adoption of new tentatives is covered earlier in the report.

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[5] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

[6] See Editorial Note, p. 414.

Subcommittee VII on Wood Poles and Cross Arms (C. D. Hocker, chairman) prepared the Tentative Methods of Conducting Static Tests of Wood Poles, referred to earlier in this report. The main purpose is to standardize the many variables so that test results will become properly comparable. Out of many test methods, the specification presents detailed description of two: (*1*) transverse bending under three-point loading in a testing machine, and (*2*) cantilever bending under a load applied at the top of a pole held horizontally by clamping the butt in a crib. The latter method is suitable for outdoor field testing.

A testing program has been formulated to provide test data intercomparing the two specification methods and the correlation of these results with fiber stress determinations obtained by laboratory machine testing of small clear specimens cut from the same poles. This first phase of testing, involving the comparison of the test methods, is planned for application to a single species of untreated timber. Further phases of testing, recognized as desirable and tentatively planned, extend the testing to several species of untreated poles and to the same species creosoted.

The magnitude of the testing program contemplated is fully appreciated, and means for its implementation are now being considered.

A project for working out tentative methods for testing the strength of cross arms is being organized.

Subcommittee VIII on Modified Wood and Wood-Base Materials (J. A. Liska, chairman) is planning to prepare a specification for modified wood. Consideration was given to the scope of the specification and the type of data to be included to make the specification of most value.

Subcommittee IX on Methods of Testing (L. J. Markwardt, chairman) considered a new tentative method of test for evaluating the properties of building boards, and recommends its acceptance as tentative. The method incorporates some previously used and established procedures, together with some modifications and revised procedures developed as a result of extensive special studies. These methods in essentially their present form have had some discussion and consideration by two international groups.

As a result of detailed international conferences and discussion in the subcommittee, a number of changes are being recommended in Standard Methods D 143, which are given earlier in this report.

Subcommittee XII on Fire-Retardant Wood (W. H. Fulweiler, chairman).—The subcommittee at a meeting in Chicago on March 14 gave consideration to the difficulties experienced in its work.

It was suggested that one method of making better progress might be to develop a cooperative program whereby under the auspices of the committee, tests would be made on lumber treated with fire-retardant solutions to at least three retentions and three minimum penetrations. This treated timber would be tested by the Underwriters' Laboratory and by the Associated Factory Mutual Laboratory test. The species used would be southern yellow pine and douglas-fir. It is believed that such a program carried on by an independent committee will yield results that would be of great assistance in the formulating of workable specifications.

There seems to be a general feeling that such a program would be desirable, but it was pointed out that the amount of business done at the present time in fire-retardant wood would probably make it difficult to secure necessary unds. The possibility of securing cooperation with committees on the same subject of the American Railway Engineering Association and the American Wood Preservers Association was also discussed.

The subject will be developed further and it is hoped it may be possible to report more substantial progress before the next meeting of the general committee.

This report has been submitted to letter ballot of the committee, which consists of 66 voting members; 43 members returned their ballots, of whom 38 have voted affirmatively, and 1 negatively.

Respectfully submitted on behalf of the committee,

L. J. MARKWARDT,
Chairman.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-7 presented to the Society through the Administrative Committee on Standards the recommendation that the Standard Specifications for Structural Wood Joist and Plank, Beams and Stringers, and Posts and Timbers (D 245 – 37) be revised and reverted to tentative, the revision being in the form of new Methods for Establishing Structural Grades of Lumber. This recommendation was accepted by the Standards Committee on September 22, 1949, and the new tentative methods appear in the 1949 Book of A.S.T.M. Standards, Part 4.

REPORT OF COMMITTEE D-8
ON
BITUMINOUS WATERPROOFING AND ROOFING MATERIALS*

Committee D-8 on Bituminous Waterproofing and Roofing Materials held two meetings during the year: one in Detroit, Mich., on June 22, 1948, during the Annual Meeting of the Society, and one in Chicago, Ill., on March 2, 1949.

Between and during these meetings the subcommittees reviewed all of the standards and tentatives for which Committee D-8 is responsible and at these meetings appropriate action was taken on the recommendations in this report.

In cooperation with Committee D-4 on Road and Paving Materials, Committee D-8 is sponsoring a Symposium on Accelerated Durability Tests of Bituminous Materials during the 1949 Annual Meeting of the Society.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1948 Annual Meeting, Committee D-8 presented to the Society through the Administrative Committee on Standards the following recommendations:

New Tentative Specifications for:

Sieve Analysis of Granular Mineral Surfacing for Asphalt Roofing and Shingles (D 1001 - 48 T).

Revision of Tentative Methods of Testing:

Asphalt Roll Roofing, Cap Sheets, and Shingles (D 228 - 47 T).

These recommendations were accepted by the Standards Committee on December 28, 1948, and the new and revised tentatives will appear in the 1949 Book of A.S.T.M. Standards, Part 3.

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the Tentative Specifications for Asphalt for Dampproofing and Waterproofing (D 449 - 47 T)[1] and for Coal-Tar Pitch for Steep Built-Up Roofs (D 654 - 42 T)[2] be approved for reference to letter ballot of the Society for adoption as standard without revision.

Committee D-8 also recommends that the Tentative Methods of Sampling Bituminous Materials (D 140 - 48 T)[3] be approved for reference to letter ballot of the Society for adoption as standard, subject to approval of Committee D-4 as these methods are under joint jurisdiction of both committees. Committee D-8 concurs with D-4 in recommending that these methods be revised by changing the minimum weight of the gross sample from "50 lb." to "2 lb." in Section 14.

ADOPTION OF TENTATIVE REVISION AS STANDARD

Committee D-8 concurs with Committee D-4 in recommending that the tentative revision of the Standard Methods of Testing Emulsified Asphalts (D 244 - 42)[2] submitted in June, 1947, be approved for reference to letter ballot of the Society for adoption as standard. This tentative revision provides a method for determination of residue by evaporation as an alternate to the present distillation method.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27-July 1, 1949.

[1] 1947 Supplement to Book of A.S.T.M. Standards, Part II.

[2] 1946 Book of A.S.T.M. Standards, Part II.

[3] 1948 Supplement to Book of A.S.T.M. Standards, Part II.

EDITORIAL CHANGES

The committee recommends that the following standards and tentatives be editorially changed, as indicated:

Standard Specifications for Bituminous Grout for Use in Waterproofing Above Ground Level (**D 170 - 41**)[2] and *for Bituminous Grout for Use in Waterproofing Below Ground Level* (**D 171 - 41**).[2]—It is recommended that the following editorial changes be made in these standards in order to make them conform to the editorial change made in Tentative Specifications D 449 in 1943 in which the designations "Type A" and "Type B" asphalts were interchanged: In Section 3 (*a*) of Specifications D 170, substitute "Type A" for "Type B" and in Section 3 (*a*) of Specifications D 171, substitute "Type B" for "Type A."

Standard Method of Test for Coarse Particles in Mixtures of Asphalt and Mineral Matter (**D 313 - 41**).[2]—The following editorial revision is recommended to clarify the calculation of results:

Section 6.—Change to read as follows:

6. The percentage of coarse particles in the mineral matter shall be calculated from the following formula:

$$\text{Percentage of coarse particles in mineral matter} = \frac{\text{Wt. of material retained on No. 200 Sieve}}{\text{Wt. of material insoluble in } CS_2} \times 100$$

Tentative Specifications for Asphalt Roofing Surfaced with Powdered Talc or Mica (**D 224 - 46 T**).[2]—The following editorial change is recommended to clarify the meaning and intent of these specifications:

Section 2.—Change to read as follows:

2. In the process of manufacture, a single thickness of dry roofing felt shall be impregnated with a hot asphaltic saturant, then coated on both sides with a hot asphaltic coating compounded with a finely powdered mineral filler, substantially insoluble in water and finally surfaced on the weather side, with powdered talc or mica. The reverse side shall be covered with suitable material to prevent the roofing from sticking in the package.

REAFFIRMATION OF STANDARDS

The committee recommends reaffirmation of the following 12 standards which have been published for six years or longer without revision:

Standard Specifications for:

Primer for Use with Asphalt in Dampproofing and Waterproofing (D 41-41),

Creosote for Priming Coat with Coal-Tar Pitch in Dampproofing and Waterproofing (D 43-41),

Coal-Tar Pitch for Roofing, Dampproofing and Waterproofing (D 450-41),

Asphalt Mastic for Use in Waterproofing (Asphalt Cement, Mineral Filler, Mineral Aggregate) (D 491-41),

Bituminous Grout for Use in Waterproofing Above Ground Level (D 170-41), with editorial changes given elsewhere in this report, and

Bituminous Grout for Use in Waterproofing Below Ground Level (D 171-41), with editorial changes given elsewhere in this report.

Standard Methods of:

Testing Bituminous Mastics, Grouts and Like Mixtures (D 147-41),

Test for Steam Distillation of Bituminous Protective Coatings (D 255-28),

Test for Sieve Analysis of Granular Mineral Surfacing for Asphalt Roofing and Shingles (D 451-40),

Test for Sieve Analysis of Nongranular Mineral Surfacing for Asphalt Roofing and Shingles (D 452-40),

Testing Films Deposited from Bituminous Emulsions (D 466-42), and

Test for Coarse Particles in Mixtures of Asphalt and Mineral Matter (D 313-41), with editorial changes given elsewhere in this report.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends the following tentatives for continuance without revision as they are all being actively studied with the probability that there will be revisions recommended in each of them before the next annual meeting of the Society:

Tentative Specifications for:

Asphalt Roofing Surfaced with Mineral Granules (D 249-46 T),

Asphalt Roofing Surfaced with Powdered Talc or Mica (D 224-46 T).

Tentative Recommended Practice for:

ccelerated Weathering Test of Bituminous Materials (D 529-39 T).

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

This report has been submitted to letter ballot of the committee, which consists of 63 voting members; 52 members returned their ballots, of whom 49 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

J. S. MILLER,
Chairman.

H. C. HOWELL,
Secretary.

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[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

REPORT OF COMMITTEE D-9
ON
ELECTRICAL INSULATING MATERIALS*

Committee D-9 on Electrical Insulating Materials held two meetings during the year and will hold a third during the Annual Meeting of the Society in June. These meetings were held in Atlantic City, N. J., on November 17, 18, and 19, 1948, and in Washington, D. C., on March 23, 24, and 25, 1949.

At these meetings actions were taken to circulate letter ballots to the committee on several new methods, new recommended practices, revisions in existing standards, and other changes in some of the standards under the jurisdiction of Committee D-9. Some projects which are still under way are mentioned later in this report.

Subsequent to the 1948 Annual Meeting, Committee D-9 presented to the Society through the Administrative Committee on Standards the following recommendations:

New Tentative Methods of:

Testing Pressure Sensitive Adhesive Tapes Used In Electrical Insulation (D 1000 - 48 T).

Revision of Tentative Methods of:

Sampling and Testing Untreated Papers Used In Electrical Insulation (D 202 - 47 T).

Tentative Revision of Standard Methods of:

Testing Pasted Mica Used In Electrical Insulation (D 352 - 39).

These recommendations were accepted by the Administrative Committee on Standards on December 22, 1948, and the new and revised tentatives together with the tentative revision of D 352 were published in the 1948 Supplement to Book of A.S.T.M. Standards, Part III-B.

Committee D-9 has approved by letter ballot during the past year revisions in the Tentative Method of Test for Rockwell Hardness of Plastics and Electrical Insulating Materials (D 785 - 48 T) which were recommended and approved last year by Committee D-20 on Plastics.

RECOMMENDATIONS AFFECTING STANDARDS

As a result of the year's work, the committee is submitting four new tentatives, revision of one standard and reversion to tentative, revisions of 9 tentatives, tentative revisions of two standards, and adoption of 9 tentatives and two tentative revisions as standard.

These recommendations have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[1]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Insulating Varnishes, Paints, and Lacquers (P. E. Demmler, chairman) has as its major project the rewriting of the Tentative Methods of Testing Varnishes for Electrical Insulation (D 115 - 48 T). The revised methods will contain procedures applicable to insulating varnishes in general, with special notes referring to some of the special types of varnish, when necessary. Particular attention is to be given to performance tests.

Extensive tests on the determination of salt-water resistance of varnish films have failed to develop a satisfactory method, and the investigation has been discontinued.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

A method for determining the set time of laminating varnishes is being developed.

The oil resistance of varnish films is being studied with particular reference to the effect of these films on transformer oil.

Round-robin tests are to be made to evaluate a method for film continuity, draining characteristics, and moisture resistance, and also on a method for determining mechanical properties by measuring creepage and deformation on a stranded cable specimen.

Subcommittee III on Plates, Tubes, Rods, and Molded Materials (G. H. Mains, chairman) has had another active year. Progress has been reported on a method of test to simulate soldering conditions for plastic tubing. Considerable time and effort has been given to the formulation of a specification for an additional electrical grade of nonrigid polyvinyl chloride. In cooperation with Committee D-20 on Plastics, an improvement of a test method for compressive strength of laminated thermosetting materials is being studied. Conditioning procedures for electrical tests on vulcanized fibre have received considerable attention. As a result of a preliminary study, the possibility of combining the Tentative Specifications for Phenolic Laminated Sheets for Radio Applications (D 467 - 44 T), and the electrical grades in the Tentative Specifications for Laminated Thermosetting Materials (D 709 - 48 T) appears to be within reason. There has been considerable discussion and work relating to a satisfactory limit for warp and twist on laminated thermosetting materials.

Subcommittee IV on Insulating Oils (E. A. Snyder, chairman).—During the past year, Section B has continued its study of the behavior of new and reclaimed transformer oils in actual transformer service. In this study, which was initiated in 1945, attempts to correlate laboratory tests with actual service life of the oil have been made. The first exhaustive summary of the large amount of data accumulated was prepared by the chairman of Section B for the March, 1949 meeting. The analysis of these data is the basis of a paper on "The Evaluation of Mineral Transformer Oil During Service: Part I, The Correlation of Oil Characteristics after 40 Months of Service,"[2] prepared by F. M. Clark, chairman of Section B. It is the general opinion that it is too early to draw any definite conclusions from this work. Certain trends have been indicated, however. It is anticipated that another five years of securing additional data will be required to produce results that can be relied upon to indicate the correlation between tests and service life.

After two years of endeavor by Section F to develop a standard method for testing oxidation stability of cable oils, it was finally decided that there was a lack of interest by both the producers and consumers of cables for such a standard test. This project was, therefore, abandoned until there is a more urgent need for it.

A successful test method for determining the quantity of water in an insulating oil has not yet been developed. There are still large discrepancies in tests between laboratories when testing oils to which a known amount of water has been added. Work is being continued in an endeavor to produce a method which is satisfactory.

Work has been started to develop a test method for determining the degree of contamination of askarels with petroleum oils.

It is anticipated that a new test method for determination of corrosive sulfur compounds in insulating oil will be available some time during the next year.

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[2] See p. 1041.

Efforts to develop an interfacial tension test method which will be acceptable for use on insulating oils have been continued. Studies are now being made to determine the possibility of using diluents which will level the curve obtained on used oils so that the break between the values obtained for good oils and poor oils will not be so abrupt.

During the year work was completed on the preparation of a screening specification for the selection of uninhibited mineral oil for use in transformers and oil circuit breakers.

Subcommittee IV is the official advisory committee to Committee No. 10 on Insulating Oils of the United States Committee of the International Electrotechnical Commission. In view of the fact that the Commission has reorganized and is starting work on the preparation of an international method to determine aging characteristics of insulating oils, Subcommittee IV is preparing for the Commission a report on developments which have occurred along these lines in this country during the war years.

During the year the subcommittee sponsored a Symposium on Insulating Oils, at which time the following papers[3] were presented:

"Performance Characteristics of Askarels," by F. M. Clark,

"Performance of Inhibited Transformer Oils," by G. H. von Fuchs,

"One System of Laboratory Testing to Appraise Serviceability of Oils in Transformers," by R. G. Call.

Subcommittee V on Ceramic Products (K. G. Coutlee, chairman).—An extensive round-robin testing program in connection with the development of electrical test methods, including electrodes for steatite and glass bonded mica under high humidity, is being carried out.

There is an apparent need for a revision of the Standard Methods of Testing Steatite Used as Electrical Insulation (D 667 – 44). A program is being formulated to develop the necessary changes in this standard to bring it up to date.

Subcommittee VI on Solid Filling and Treating Compounds (W. A. Evans, chairman).—Several new test methods are now under consideration. Among these are a test method for oil solubility and a test method for determining the flexibility of microcrystalline waxes. For the latter the use of a modified plastics flexibility test has been proposed.

Subcommittee VII on Varnished Fabrics (R. W. Chadbourn, chairman).—As mentioned in the 1948 report[4] of Committee D-9 this subcommittee is reviewing the dielectric strength requirements for varnished cloth tapes under 6 per cent elongation in Specifications D 373. One of the chief controversial points is in connection with 7 mil tapes.

The question of what shall be considered the proper terminology for flexible treated cotton and rayon sleeving used in electrical insulation in Tentative Specifications D 372 has been settled, based on the following explanation: "To call a lacquered braided sleeving a 'varnished tubing' is misleading and causes confusion, the term "varnished tubing" should be confined to a sleeving treated with an oil varnish. The term 'treated sleeving' can be applied generally to both types, oil varnished and lacquered sleeving, without causing confusion. Braided sleeving is not generally considered to be a tube."

Editorial changes in the Standard Methods of Testing Flexible Varnished Tubing Used for Electrical Insulation (D 350 – 48) are under consideration.

The Section on Treated Glass Fabrics is continuing its investigation to determine the effect of heat on the flexibility of treated glass tapes. The first round-robin series of tests revealed that the dielectric strength test was the best criterion of aging of the test specimens undergoing heat conditioning.

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[3] Issued as a separate publication, *STP No. 95*, December, 1949.

[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 48, p. 402 (1948).

Subcommittee VIII on Insulating Papers (E. G. Ham, chairman).—The Chemical Test Section is making progress toward the adoption of methods for determining the water and alcohol soluble matter in papers as well as of soluble sulfates in paper. Progress has been reported in the revision of the deterioration test for insulating paper in Tentative Methods D 202. Statements on the significance of the test methods for weight, air resistance, bursting strength, tensile strength, thickness, and tearing strength or internal tearing resistance of untreated electrical insulating paper have been prepared for Methods D 202 and should be ready for committee action some time during the coming year. Other test procedures in Methods D 202 will receive attention, and statements on significance of tests will be prepared.

The Section on Insulating Papers made several noteworthy improvements in the proposed specification for absorbent insulating papers. This has been made possible by active interest and important contributions by both the producers and consumers active in this section.

The Joint D-6 - D-9 Committee on pH Problems has prepared a test method applicable to vulcanized fibre which will be submitted simultaneously to Subcommittee III for approval. This joint committee is also preparing changes in the pH procedure to include reference to the Tentative Method for pH of Aqueous Solutions with the Glass Electrode(E 70 - 46 T) in so far as it is possible.

Subcommittee IX on Mica (E. O. Hausmann, chairman). —Considerable time and effort have been spent in obtaining agreement throughout the mica industry on the mica samples which are to represent the different visual classifications of natural mica. Agreement has been reached on all except one of these and the subcommittee has decided to proceed without complete agreement. Photographic transparencies are to be made from these mica samples as soon as sufficient orders have been received to justify their production. More than half of the required number of orders have been received to date. The Standard Methods of Testing, Grading and Classifying Natural Mica (D 351 - 46) are being revised to include the use of these transparencies. The subcommittee is cooperating with the Indian Standards Institutions and with the International Organization for Standardization on standardization problems in connection with mica.

Subcommittee X on Conditioning (A. C. Webber, chairman) serves both Committees D-9 and D-20 on matters referring to conditioning.

During the past year the subcommittee has been reorganized and its membership brought up to date. The roster has been officially established as comprising all chairmen of D-9 and D-20 subcommittees or their appointed representatives and other committee members who may wish to participate actively in the work of the subcommittee. The current membership list includes 35 members. Principal activities of the subcommittee during the past year are reflected in the revisions pertaining to conditioning as given in the Appendix. In addition to these actions, the subcommittee has under consideration such related problems as apparatus for measuring humidity, standardization of subnormal and supernormal test conditions and conditioning times.

Subcommittee XI on Significance of Tests (J. H. Palmer, chairman).—During the year this subcommittee has reviewed the significance of test statements prepared by several other subcommittees. The chief controversial point that has been considered by this subcommittee is the general form and arrangement of these statements. The subcommittee now is balloting its members on a proposed Recommended Practice for Writing Statements as to the Usefulness of Tests of Electrical Insulating Material (Revised November, 1948). This includes both statements for general utility and for specific utility.

Subcommittee XII on Electrical Tests (K. N. Mathes, chairman).—During the past year Section A on Insulation Resistance continued to hold several meetings and has proposed a comprehensive revision of the Standard Methods of Test for Insulation Resistance of Electrical Insulating Materials (D 257 - 46). The section proposes that these revised methods be published as tentative, superceding the present Standard Methods D 257. The Section has under way a further project on preferred procedures for tests of electrical resistance of insulating materials intended to be supplementary to the revised Method D 257.

The problem of measuring dielectric constant and dissipation factor of aviation fuels over a wide temperature range has received consideration. There is an apparent need for a new test cell or bomb that will permit testing such fuels over a varied set of test conditions. This matter is being discussed with Committee D-2 on Petroleum Products and Lubricants.

A round-robin test program for dielectric loss at expected frequencies as high as 30,000 mc. is under way. The work on this series of tests will serve as a basis of an extensive revision of the Tentative Methods of Test for Power Factor and Dielectric Constant of Electrical Insulating Materials (D 150 - 47 T).

Several new arc-resistance test methods are under consideration, including one on a high-energy arc.

This report has been submitted to letter ballot of the committee, which consists of 151 voting members; 78 members returned their ballots, of whom 77 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

C. T. HATCHER,
Chairman.

E. A. SNYDER,
Vice-Chairman.

O. E. ANDERSON,
Recording Secretary.

APPENDIX

RECOMMENDATIONS AFFECTING STANDARDS FOR ELECTRICAL INSULATING MATERIALS

In this Appendix are given recommendations affecting certain standards and tentatives covering electrical insulating materials which are referred to earlier in this report. The standards and tentatives appear in their present form in the 1946 Book of A.S.T.M. Standards Part III-B, or the 1947 and 1948 Supplements, Part III-B, as indicated by the final number in the A.S.T.M. designation.

NEW TENTATIVES

Tentative Recommended Practice for the Purchase of Uninhibited Mineral Oil for Use in Transformers and Oil Circuit Breakers:

This recommended practice is intended as a screening specification on the basis of certain physical, electrical, and chemical characteristics of one or more brands of oil suitable for further investigation. It is recommended that this recommended practice, as appended hereto,[1] be accepted for publication as tentative.

Tentative Methods of Testing Glass Bonded Mica Used as Electrical Insulation:

These methods provide procedures for making various tests when they are required for an investigation or examination of glass bonded mica used as electrical insulation. It is recommended that these methods, as appended hereto,[1] be accepted for publication as tentative.

Tentative Recommended Practice for Maintaining Constant Humidity by Means of Aqueous Solutions:

This recommended practice provides procedures suitable for obtaining constant relative humidities ranging from 30 to 98 per cent at temperatures from 0 to 70 C. in a small airtight container. Committee D-9 joins with Committee D-20 on Plastics in recommending that this practice, as appended hereto,[1] be accepted for publication as tentative.

REVISION OF STANDARD AND REVERSION TO TENTATIVE

Tentative Methods of Test for Electrical Resistance of Insulating Materials:

This method is an extensive revision of the present Standard Methods of Test for Insulation Resistance of Electrical Insulating Materials (D 257 - 46). It is recommended that these methods, as appended hereto,[2] be accepted for publication as tentative.

REVISIONS OF TENTATIVES

Tentative Specifications for Phenolic Molding Compounds (D 700 - 45 T):

The revision of these specifications consists of an addition of three new types of phenolic molding compounds along with an elimination of a single type. The revised specifications, appended hereto,[2] cover twelve types of phenolic molding compounds. Committee D-9 concurs in this revision as proposed by Committee D-20.

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[1] These methods and recommended practices were accepted as tentative by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 6.

[2] These revised methods and specifications were accepted as tentative by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 6.

Tentative Specifications for Laminated Thermosetting Materials (D 709 - 48 T):

The revision consists of the addition of the physical and electrical properties of the various glass-base grades of laminates under type IV classification of these specifications.

Table I.—Add the following for a new type IV:

Type IV.
Grades G1, G2, G3, and G5.
Sheets, add reference letter *a*.

Section 4.—Add the following to the table in Note 9:

Type IV.
Grades G1, G2, G3, and G5.
Color, natural.

Table III.—Add the following requirements for type IV:

	Type IV		
	Grades G1 and G2	Grade G3	Grade G5
Tensile strength, min., psi.	7 500	17 000	20 000
Flexural strength, min., psi	15 000	17 000	25 000
Compressive strength, min., psi. (flatwise)	33 000	38 000	50 000
Impact strength (Izod), ft-lb. per in. of width:			
Flatwise	3.5	6.0	12.0
Edgewise	3.3	5.0	5.5
Power factor at 1,000,000 cycles, max.	0.032	0.035	0.020
Dielectric constant at 1,000,000 cycles, max.	5.5	6.0	7.7
Loss factor at 1,000,000 cycles, max.	0.18	0.21	0.15

Table IV.—Add the following requirements for type IV:

Type IV	Thickness, in.	Dielectric Strength Perpendicular to Laminations, min., v. per mil	
		Short Time Test	Step-by-Step Test
Grades:			
G1 and G2	$\frac{1}{32}$ to $\frac{1}{16}$, incl.	200	120
	Over $\frac{1}{16}$ to $\frac{1}{8}$ incl	150	90
G3	$\frac{1}{32}$ to $\frac{1}{16}$ incl.	350	210
	Over $\frac{1}{16}$ to $\frac{1}{8}$, incl.	275	170
G5	$\frac{1}{32}$ to $\frac{1}{16}$, incl.	275	170
	Over $\frac{1}{16}$ to $\frac{1}{8}$, incl.	220	140

Table V.—Add the following requirements for type IV:

	Water Absorption After 24-hr. Immersion, max., per cent		
	Type IV		
Grade	G1, 2	G3	G5
Thickness, in.			
$\frac{1}{16}$	3.00	3.50	3.30
$\frac{1}{8}$	2.30	2.50	2.75
$\frac{1}{2}$	1.20	1.80	2.00

Tentative Specifications for Vulcanized Fibre Sheets, Rods, and Tubes Used for Electrical Insulation (D 710 - 47 T):

The following revisions are descriptive changes which include the available colors and thickness range applicable to each of the three grades of vulcanized fibre covered in these specifications:

Section 3.—Change to read as follows:

3. Three grades of vulcanized fibre are covered, as follows:

Bone Grade.—This grade is characterized by the greater hardness and stiffness associated with higher density. It machines smoother and with less tendency to separate the plies in difficult machining operations. It is made in gray color only and in the limited thickness range of $\frac{1}{32}$ to $\frac{1}{2}$ in.

Commercial Grade.—This grade is considered as the general-purpose grade and is sometimes referred to as mechanical and electrical grade. It possesses good physical and electrical properties and can be fabricated satisfactorily by punching, turning, and forming operations. It is made in all standard colors and through the entire range of thicknesses from 0.004 to 2 in.

Electrical Insulation Grade.—This grade is primarily intended for electrical applications and others involving difficult bending or forming operations. It is made in gray color only and in all standard thicknesses from 0.004 to $\frac{1}{8}$ in. Thin material of this grade is sometimes referred to as "fish paper."

Tentative Specifications for Nonrigid Vinyl Chloride Plastics (D 744 - 44 T):

This tentative is under the jurisdiction of Committee D-20. It is now proposed to add electrical grades of material, thereby bringing this specification under a possible Joint D-9 and D-20 jurisdiction. It is recommended that the following revisions be accepted, subject to concurrence of Committee D-20:

Table I.—Make the following additions to this table:

	Grades 10, 11, 12, and 13
Type V, Electrical:	
Durometer Hardness	...
A.S.T.M. Hardness	...
Low-Temperature Classification	...

Table II.—Make the following additions to this table:

	Type V			
	Grade 10	Grade 11	Grade 12	Grade 13
Specific gravity, 25/25 C. (77/77 F.) max.	1.50	1.50	1.50	1.50
Specific gravity, 25/25 C. (77/77 F.) min.	1.30	1.30	1.30	1.30
Tensile strength, min., psi	1500	1500	1500	1500
Elongation at rupture, min., per cent	200	200	200	200
Tear resistance, min., lb. per in.	300	275	250	275
Weight loss on heating, max., per cent	*d*	*d*	*d*	*d*
Increase in stiffness at 23 C. (73.4 F.) after heating, max., per cent	*d*	*d*	*d*	*d*
Thermal stability, max., mg. HCl per g.	2	2	3	2
Dielectric strength (short-time test), min. v. per mil	350	350	300	350
Deformation under load, 100 psi. pressure at 70 C. (158 F.):				
Total deformation, max., per cent	35	35	40	35
Recovery, min., per cent	65	65	65	65
D-c. voltage resistance at 50 C., ohm cm., min.	1×10^{12}	1×10^{10}	1×10^{9}	1×10^{9}
Dissipation factor, 60 cycles, 50 C., max.,[c]	0.07	0.14	0.2	0.3
Dielectric constant, 60 cycles, 50 C., max.,[c]	10	12	12	12
Brittle temperature deg. C.	*b*	*b*	−40	*b*
Brittle temperature deg. F.	*b*	*b*	−40	*b*
Flammability	*d*	*d*	*d*	*d*

[b] To be specified at a later date.
[c] Higher temperature values to be added later.
[d] To be specified after development of suitable methods.

Tentative Methods of Testing Vulcanized Fibre Used for Electrical Insulation (D 619 – 46 T):

The revision of these methods covers the inclusion of the newly developed bond strength test.

New Section.—Add the following as a new Section 15 under the general heading "methods applicable to sheets," renumbering the subsequent sections accordingly:

15. *Bond Strength (Ply Adhesion)*.—Bond strength (ply adhesion) shall be determined in accordance with the Tentative Method of Test for Bond Strength of Plastics and Electrical Insulating Materials (A.S.T.M. Designation: D 952).

Tentative Methods of Test for Flexural Properties of Plastics (D 790 – 45 T):

These revisions are essentially provisions to take care of testing thin specimens in flexure.

Section 3 (a).—Change the fourth sentence to read as follows: "The width of the specimen shall be in accordance with Table I."

Note 1.—Delete this note, renumbering subsequent notes accordingly and add a new Note 4 as follows:

NOTE 4.—The rate of crosshead motion in inches per minute for flatwise tests of 1/32-in. sheet materials may be chosen as 0.025 in. per min. to shorten the time of test.

Table I.—Change to read as follows:

TABLE I.—SUGGESTED DIMENSIONS FOR TEST SPECIMENS.

Nominal Thickness of Sheet, in.	Span, min., in.	Flatwise		Edgewise	
		Depth of Specimen, in.	Width of Specimen, in.	Depth of Specimen, in.	Width of Specimen (Nominal Thickness), in.
1/32	½	1/32	1		
1/16	1	1/16	1	1/16	1/16
3/32	1½	3/32	1	3/32	3/32
⅛	2	⅛	1	⅛	⅛
3/16	3	3/16	½	3/16	3/16
¼	4	¼	½	¼	¼
⅜	6	⅜	½	⅜	⅜
½	8	½	½	½	½
¾	12	¾	¾	¾	¾
1	16	1	1	1	1
1½	24	1½	1½	1½	1½
2	32	2	2	2	2

Section 6 (b).—Insert a reference to Note 4 at the end of this paragraph.

Add a note to this section as follows:

NOTE.—The breaking loads of certain sheet materials in 1/32-in. thickness may be lower than 60 lb. Some testing machines have poor accuracy at such loads, and it may be advisable to obtain a greater degree of accuracy by magnifying the load about 10-fold by a lever system. Details of such a lever system are given in the University of Delaware Report UD-P-12 of October 6, 1948, entitled "Flexure Testing of Thin Laminated Plastics."

Insert a reference to this note at the end of Section 2 *(a)*.

Tentative Methods of Testing Varnished Cloths and Varnished Cloth Tapes Used in Electrical Insulation (D 295 – 47 T):

These revisions provide for the addition of significance of test statements for weight and thickness of varnished cloths and varnished cloth tapes and for the use of the newly developed slow-rate-of-rise dielectric strength test as an alternate step-by-step dielectric strength test.

New Sections.—Under their respective headings in this method add the following statements on definitions and significance of conditioning, thickness, breaking strength, dielectric strength, elongation, resistance to oil, weight, and threads per inch, renumbering the present sections accordingly:

Definition.—Conditioning of varnished cloth or varnished cloth tape may be defined as the process of subjecting the material to a specified temperature and a specified relative humidity for a stipulated period of time.

Significance.—*(a)* Because the physical and electrical properties of most fabrics change with variation of their moisture content, it is necessary to control this property at the time of testing in order to attain reasonably good reproducibility of test values. For example, when cotton fabric absorbs moisture, it tends to swell and increase in dimensions. Also, the flexibility, elongation, and tensile strength of the material normally increases with increased relative humidity whereas conversely the electrical properties are depreciated when the material is subjected to these conditions. The time of exposure to the conditioned atmosphere must be long enough to permit the moisture content of the test specimen to reach a relatively stable value. If the fabric is untreated, a few hours exposure is sufficient. Treated fabrics like varnished cloth require an appreciably longer time.

(b) The significance of conditioning for insulation resistance and power factor tests is outlined in the general statements, "Significance of the Resistivity Test," and "Significance of the Power Factor Test," respectively.

Definition.—Thickness of varnished cloth and varnished cloth tape is the perpendicular distance between the outer varnished surfaces of the material as determined in accordance with this method.

Significance.—This test is of value in determining whether the material meets specified tolerances for thickness. In addition, thickness values are essential because of the importance of space factor in designing electrical equipment.

Determination of dielectric strength, usually expressed in volts-per-mil, also necessitates thickness measurements.

Definition.—The breaking strength of varnished cloths and varnished cloth tapes may be defined as the force required to break the cloth or tape when tested under certain prescribed conditions.

Significance.—The breaking strength of finished cloth and tape is of importance as a measure of its ability to withstand reasonable pulling without failure while being applied in service.

Definition.—The dielectric strength of varnished cloth or tape may be defined as the maximum potential gradient, usually expressed in volts-per-mil, that the material can withstand without rupture, when the cloth or tape is electrically stressed between two electrodes under prescribed conditions.

Significance.—Dielectric strength of varnished cloth or tape insulating material is of significance for the following reasons:

(a) Insulating materials are subjected to such electrical stresses in service for long periods of time. Although these service stresses are usually a small fraction of the breakdown stresses determined by dielectric strength tests, it has been found that, for any given material, the service stresses which it can withstand during its life bear some relation to the breakdown stresses obtained in the dielectric strength test. This test, therefore, gives some indication of the ability of the cloths or tapes to withstand the service stresses to which they are subjected.

(b) This test often detects the presence of defects in the cloth or varnish, although it is inadequate for this purpose since only a small part of the surface is explored.

(c) This test is of value in determining the ability of the cloth or tape to withstand conditions of elongation and hot oil, encountered in

some service applications, without excessive loss of dielectric strength.

(*d*) Three methods of testing for dielectric strength are given, the short-time, the step-by-step, and the endurance tests. Choice of the method should be based on whether or not the effect of time under stress is considered an important factor, and the available time which can be allowed for each test. See also the general statment, "Significance of the Dielectric Strength Test."

Definition.—The amount of stretch observed in a given length of varnished cloth or tape when subjected to prescribed loading conditions at prescribed atmospheric conditions is specified as the elongation of the cloth or tape. It is expressed in per cent of the initial length.

Significance.—Elongation of a varnished cloth or tape insulation is important as a measure of the ability of the insulation to conform to the contours of even and uneven surfaces without damaging the varnished film. Tapes that do not have sufficient elongation may be difficult to apply satisfactorily, and tapes that elongate too much may destroy the varnish film and thereby cause a decrease in its dielectric strength.

Definition.—The oil resistance of varnished cloth or tape is the ability of the varnish film to withstand the attack of mineral oil without excessive impairment of its physical and electrical characteristics when the varnished cloth or tape is immersed in a specified oil for a prescribed period of time at a given temperature.

Significance—(*a*) The oil resistance of varnished cloth or tape determines the suitability of the insulation for use in oil-immersed apparatus, such as oil-filled transformers and switches, and in electric cables and cable splices. It will also serve to indicate serviceability in proximity to lubricating oils. Such oils, however, usually have very little effect on a varnish film as compared with transformer oil.

(*b*) When immersed in oil, black varnish films usually soften and swell slightly, but they should not blister, wrinkle, nor separate from the cloth. Yellow varnish films are much more oil resistant than black films and soften and swell very little, if any. In either case, the dielectric strength should not be impaired.

Definition.—The weight of varnished cloth and varnished cloth tapes is the weight per unit area as determined in accordance with this method. It is usually expressed in pounds per square yard, for a specified nominal thickness.

Signifícnce.—The ratio of varnish weight to cloth weight, within and between shipments, can be determined from the weight of varnished cloth or varnished cloth tape and the weight of the cloth base. This ratio is a factor in determining the electric characteristics of the material.

Weight values are useful for estimating weight in designing electrical equipment containing a constituent part of varnished cloth or tape.

Definition.—The threads per inch of varnished cloth refer to the count of the number of warp and filling yarns present in the base cloth per linear inch of length or width.

Significance—(*a*) Thread count, together with the weight and the width of the cloth, is accepted as the common means for designating and identifying cloth constructions.

(*b*) Certain of the physical and electrical properties of woven fabrics are dependent on thread count. That is, assuming the same size of yarn, an increase in thread count increases the weight, breaking strength, and density of the cloth. Also, the dielectric strength and power factor of the varnished fabric may be changed by altering the number of threads per inch of the cloth.

Change the subheading under Dielectric Strength to read "short-time, step-by-step and slow-rate-of-rise tests."

Section 14.—Change to read as follows:

14. The purpose of the procedure is to determine the dielectric strength of varnished cloths and varnished cloth tapes when subjected to a short-time, step-by-step or slow rate-of-rise test.

Section 20.—Change Paragraph (*a*) to read as follows and add a new Paragraph (*d*) to read as indicated:

(*a*) Tests shall be made by either the short-time test or by the step-by-step test or its alternate, the slow rate-of-rise test, or by both methods.

(*d*) In the slow rate-of-rise test, the starting voltage shall be 850 v. per mil of thickness, or as otherwise specified, and the voltage shall be raised uniformly at one of the following rates, or as otherwise specified:

Tape Thickness	
8 mils or less..................	13 v. per sec.
Over 8 mils....................	25 v. per sec.

Tentative Methods of Sampling and Testing Untreated Paper Used in Electrical Insulation (D 202 - 48 T):

These revisions provide for conditioning specimens in 50 per cent relative humidity at 23 C. and the addition of a method for determining stretch under tension.

Section 3 (a).—Change the first two sentences to read as follows: "Samples shall be conditioned in air at 50 ± 2 per cent relative humidity at a temperature of 23 ± 2 C. (73.4 ± 3.6 F.)

Add the following new method after the procedure for tensile strength:

> 11. *Stretch Under Tension*.—Stretch under tension shall be determined in accordance with the Tentative Method of Test for Stretch of Paper and Paper Products Under Tension (A.S.T.M. Designation: D 987), except that the material shall be sampled and conditioned in accordance with Sections 2 and 3 of these methods.
>
> NOTE.—This method is unsuitable for use in testing creped papers. A modified procedure will be devised for this special requirement.

New Method of Test for the Aqueous Extract Conductivity of Paper Used in Electrical Insulation.—At the end of the present methods add as Sections 65 to 71, a complete test procedure for aqueous extract conductivity of paper, as appended hereto.[1] This method has been developed for the estimation of the electrolyte content of paper by measurement of the electrical conductivity of an aqueous extract.

Tentative Methods of Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 - 47 T):

This revision is a change in the definition of a standard laboratory atmosphere and, likewise, there will be a change in one of the standard test temperatures.

Section 2 (a).—Change to read as follows:

> 2. (*a*) *Standard Laboratory Atmosphere*.—An atmosphere having a relative humidity of 50 ± 2 per cent at a temperature of 23 ± 1.1 C. (73.4 ± 2 F.).

Section 2 (c).—In the table listing the standard test temperatures, change "25 C. (77 F.)" to "23 C. (73.4 F.)."

TENTATIVE REVISIONS OF STANDARDS

Standard Methods of Testing Laminated Tubes Used in Electrical Insulation (D 348 - 46):

The following revision of the existing tentative revision of this standard consists of a redesigned test specimen and metal plugs for making tension tests of laminated tubes so that failure will occur within the flat section of the specimen.

Section 5.—Change to read as follows:

> 5. The test specimen shall be as shown in Fig. 2.[3] The length, *L*, shall be as shown in the table under Fig. 2. A groove shall be machined around the outside of the specimen at the center of its length to a depth of 40 per cent of the nominal wall thickness. This groove shall consist of a straight section $2\frac{1}{4}$ in. in length with a radius of 3 in. at each end joining it to the outside diameter. Steel or brass plugs having diameters such that they will fit snugly inside the tube and having a length equal to the full jaw length plus 1 in. shall be placed in the ends of the specimen to prevent crushing. They can be located in the tube conveniently by separating and supporting them on a threaded metal rod. Details of plugs and test assembly are shown in Fig. 2.

Standard Methods of Testing Laminated Round Rods Used in Electrical Insulation (D 349 - 46):

The following revision of the existing tentative revision of this standard consists of a redesigned test specimen for making tension tests of laminated rods so that failure will occur within the flat section of the specimen.

Section 4.—Change to read as follows:

> 4. The test specimen shall be as shown in Fig. 3.[3] The length, *L*, shall be as shown in the table under Fig. 3. A groove shall be machined around the specimen at the center of its length to a depth of 20 per cent of the original nominal diameter. This groove shall consist of a straight section $2\frac{1}{4}$ in. in length with a radius of 3 in. at each end joining it to the outside diameter.

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[3] See p. 490 for these figures which are the same as recommended for the Tentative Method of Test for Tensile Properties of Plastics (A.S.T.M. Designation: D 638).

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following nine tentatives be approved for reference to letter ballot of the Society for adoption as standard without revision:

Tentative Specifications for:

Low and Medium Voltage Pin-Type Lime-Glass Insulators (D 730 - 46 T),
Natural Block Mica and Mica Films Suitable for Use in Fixed Mica-Dielectric Capacitors (D 748 - 47 T),
Enclosures for Small Testing Machines for Tests at Subnormal and Supernormal Temperatures of Electrical Insulating Materials and Plastics (D 760 - 44 T),
Servicing Units for Tests at Subnormal and Supernormal Temperatures of Electrical Insulating Materials and Plastics (D 761 - 44 T),
Communication and Signal Pin-Type Lime-Glass Insulators (D 879 - 46 T).

Tentative Methods of:

Test for Dielectric Strength of Insulating Oil of Petroleum Origin (D 877 - 46 T),
Test for Inorganic Chlorides and Sulfates in Insulating Oil (D 878 - 46 T),
Sampling Electrical Insulating Oils (D 923 - 47 T), and
Test for Power Factor and Dielectric Constant of Electrical Insulating Oils of Petroleum Origin (D 924 - 47 T).

ADOPTION OF TENTATIVE REVISIONS AS STANDARD

Standard Methods of Testing Sheet and Plate Materials Used in Electrical Insulation (D 229 - 46):

The committee recommends that the tentative revisions[4] of the hardness test, Sections 36 to 39, of this standard submitted in June, 1944, and modified in September, 1947, be approved for reference to letter ballot of the Society for adoption as standard. In the text of the method when revised designate the new method as Procedure A and the present procedure as Procedure B.

Standard Methods of Testing Pasted Mica Used in Electrical Insulation (D 352 - 39):

The committee recommends that the tentative revision[4] of this standard pertaining to Section 14 (*a*) and (*b*), submitted in December , 1948, be approved for reference to letter ballot of the Society for adoption as standard.

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[4] 1948 Supplement to Book of A S.T.M. Standards, Part III-B.

REPORT OF COMMITTEE D-10

ON

SHIPPING CONTAINERS*

Following the custom of recent years, Committee D-10 on Shipping Containers held two meetings during the past year. The fall meeting was held in Chicago, Ill., on October 8, 1948, and was preceded by a full day of well-attended subcommittee meetings. In addition to receiving the reports of the subcommittees, a paper was presented by Mr. A. B. Perry, Chief Field Engineer, Signode Steel Strapping Co., on "The Function of a Test Track in Developing Good Packaging and Carloading Methods."[1] The members were guests of the General Box Co. for a demonstration of a box testing laboratory.

The spring meeting was held at Atlantic City, N. J. on May 10, 1949, and followed a day of subcommittee work. Much work was accomplished.

The meeting passed unanimously a resolution on the loss to the Society of its very capable and active late member, C. G. Weber.

At the present time, the committee consists of 79 members, of whom 28 are classified as producers, 31 as consumers and 20 as general interest members.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1948 Annual Meeting, Committee D-10 presented to the Society through the Administrative Committee on Standards the following recommendations:

New Tentative Methods of:

Drop Test for Cylindrical Shipping Containers (D 977 – 48 T)
Test for Penetration of Liquids into Submerged Containers (D 998 – 48 T)
Vibration Test for Shipping Containers (D 999 - 48 T)

New Tentative Definitions:

Terms Relating to Shipping Containers (D 996 - 48 T)

The date of approval for Definitions D 996 was August 3; Methods D 997 and D 999, September 29; and Method D 998, November 15. The new tentatives appear in the 1948 Supplement to Book of A.S.T.M. Standards, Part III-B.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following tentatives be retained in their present status without revision:

Tentative Methods of Test for:

Water Vapor Permeability of Packages (D 895 - 47 T), and
Water Resistance of Containers by Spray Method (D 951 – 47 T).

This report has been submitted to letter ballot of the committee, which consists of 79 members; 46 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

T. A. CARLSON,
Chairman.

EARL R. STIVERS,
Secretary.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27-July 1, 1949.

[1] ASTM BULLETIN, No. 155, December, 1948, p. 38.

REPORT OF COMMITTEE D-11
ON
RUBBER AND RUBBER-LIKE MATERIALS[*]

Committee D-11 on Rubber and Rubber-Like Materials held one meeting during the year in Chicago, Ill., on March 4, 1949, in connection with the Spring Group meetings of A.S.T.M. committees. The subcommittees, however, have been active throughout the year and have carried on their work vigorously through correspondence and separate meetings as required.

At the Spring Meeting of the Society held in Chicago on March 2, 1949, the committee through its Subcommittee XV on Life Tests sponsored the technical program which consisted of a symposium of six papers on "Aging of Rubbers."[1] These papers, by leaders in their fields, were of outstanding value in presenting the latest information on the difficult problems involved in evaluating and controlling the aging effects of air, sunlight, heat, and ozone on different types of rubber compositions. The symposium was especially valuable in bringing together available information on the newer types of synthetic rubbers.

Committee D-11 is participating in the activities of the International Organization for Standardization, Technical Committee 45 on Rubber, and was represented by H. G. Bimmerman at its meetings in London, England, on June 28 and 29, 1948. The committee has voted to recommend that I.S.O. Technical Committee 45 be invited to meet at Atlantic City, N. J. in connection with the 1950 Annual Meeting of the Society.

Committee D-11 has become increasingly aware of the extensive work which is in progress in A.S.T.M. committees and in other agencies on the investigation of properties of elastomeric and plastic materials at low temperatures and on methods for evaluating these properties. The committee believes that there is a serious need for coordination of these activities and wishes to recommend that a technical committee be established within Committee E-1 on Methods of Testing to serve as a coordinating group for the standardization work in this field which is currently in progress in Technical Committees D-9 on Electrical Insulating Materials, D-20 on Plastics, and D-11; also in various Government agencies, and other groups.

Committee D-11 has been cooperating with the National Bureau of Standards, through a special committee on standard reference samples of rubber compositions and rubber compounding ingredients, in the development of a program whereby such materials would be made available by the Bureau to serve as laboratory standards for the rubber industry. As a result of this program, the National Bureau of Standards has now made available a series of seven compounding ingredients as follows:

Standard Sample	Name	Weight per Package, g.
No. 370....	Zinc oxide	2000
No. 371....	Sulfur	1000
No. 372....	Stearic acid	600
No. 373....	Benzothiazyl disulfide	600
No. 374....	Tetramethylthiuram disulfide	600
No. 375....	Channel black	8000
No. 376....	Light magnesia	140

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[*] Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] Symposium on Aging of Rubbers, Chicago Spring Meeting, Am. Soc. Testing Mats., (1949). (Symposium issued as separate publication, *ST No. 89.*)

As a further step in this program, there is now under consideration a series of thirteen typical rubber compound formulations from which standardized rubber samples may be made available when agreement is reached. Committee D-11 has also been actively cooperating with the Federal Specifications Board in an extensive revision of the Federal Specification ZZ-R-601a covering Methods of Physical Tests and Chemical Analyses of Rubber Goods.

PROPOSED SPECIFICATIONS FOR LATEX

Proposed Specifications and Methods of Test for Concentrated, Ammonia Preserved, Creamed and Centrifuged Natural Rubber Latex.—These proposed specifications were discussed in the 1948 Report[2] at which time it was expected that they would be ready for immediate publication. However, several points came into controversy, the resolution of which prevented earlier publication. Agreement has now been reached and it is proposed to proceed as indicated in the 1948 Report. These proposed specifications are accordingly presented in the Appendix as information.[3]

NEW TENTATIVES

The committee recommends the acceptance for publication of the following ten new tentatives:

Tentative Specifications for Thermoplastic Vinyl Polymer Sheaths for Electrical Insulated Cords and Cables.[4]—These specifications have been developed by Subcommittee V on Insulated Wire and Cable to cover the increasing use of vinyl polymer materials as a replacement for rubber in sheaths of electrical cords and cables. These specifications are based on extensive experience by members of the committee in the manufacture and use of vinyl polymer sheaths, and, in recommending them, it is felt that a very real need will be served.

Tentative Specifications for Rubber Insulating Line Hose (Proof Test, 20,000 volts, three minutes), for Rubber Insulator Hoods (Proof Test, 20,000 volts, three minutes), for Rubber Insulating Sleeves (Proof Test, 10,000 volts, three minutes), and for Rubber Insulating Blankets (Proof Test, 10,000 volts, three minutes).[4]—The above four specifications covering rubber electrical protective equipment are the outgrowth of work done during the war in the American Standards Association. That work resulted in the development of a group of standard specifications for rubber safety equipment which were urgently needed and were adopted through the ASA procedure as American war standards. These specifications were sent to over four hundred users for comment and criticism prior to adoption as war standards. With the end of the war and under the policy of the American Standards Association to withdraw the war standards, the feeling arose that these specifications for rubber electrical protective equipment should become A.S.T.M. standards. Subcommittee IV which is organized as Sectional Committee J6 on Specifications for Protective Equipment for Electrical Workers under the ASA procedure has undertaken the task of revising these former war standards for A.S.T.M. It is planned that these specifications as finally agreed upon will be presented to both agencies. In their final form they represent a vast fund of experience and consideration of existing standards.

Tentative Specifications and Methods of Test for Latex Foam Rubbers, and Tentative Specifications and Methods of Test for Sponge and Expanded Cellular Rubber

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[2] *Proceedings*, Am. Soc. Testing Mats , Vol 48, p 425 (1948).

[3] Subsequent to the June meeting, Committee D-11 presented these specifications to the Society as tentative, see Editorial Note, p. 440.

[4] These specifications and methods were accepted as tentative by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 6.

Products.[5]—The above two new tentatives represent a complete revision of the Tentative Specifications for Cellular Rubber Products (D 798 - 46a T) and the Tentative Methods of Testing Cellular Rubber Products (D 552 - 46a T). In reviewing and revising the two existing tentatives, it has been felt that the utility of the cellular rubber standards would be increased if they were classified according to the product rather than as specifications or methods of test as the product classification more nearly follows the pattern of manufacture and use. The committee believes that the revisions and rearrangement represent distinct improvement in these tentatives and recommends that the present Methods D 552 and Specifications D 798 be withdrawn and replaced by these new tentatives.

Tentative Method of Test for Resistance of Vulcanized Rubber or Synthetic Elastomers to Cut Growth by the Use of the Ross Flexing Machine.[4]—This equipment and method have been adopted generally by the manufacturers of rubber soling material for evaluation of that type of product. It could also be used for any type of sheet rubber of appropriate thickness. A standardized procedure for conducting these tests is needed and Subcommittee XVIII has prepared this method for publication as tentative.

Tentative Method of Measuring Low-Temperature Stiffening of Rubber and Rubber-Like Materials by the Gehman Torsional Apparatus.—This tentative was presented as a proposed method in the 1948 Report[2] of Committee D-11. While a few minor revisions may be necessary in the future, the committee wishes at this time to recommend its publication as tentative.

Tentative Method of Test for Impact Resilience and Penetration of Rubber by the Rebound Pendulum.—This was published as a proposed method of test in the 1949 D-11 Compilation[6] and is now recommended for publication as tentative.[4] Standardized methods for determining the impact resilience properties of rubber had been needed for some time. The rebound pendulum (Goodyear-Healey apparatus) required in this proposed procedure has met with considerable acceptance and is now commercially available. This new method as developed by Subcommittee XXVII is therefore based on considerable experience by members of the committee with the use of the equipment and its publication as tentative will greatly aid in the standardization of this type of test.

REVISIONS OF TENTATIVES

The committee recommends that the following five tentatives be revised as indicated and continued as tentative:

Tentative Methods of Testing Rubber Hose (**D 380 - 46 T**).[7]—This revision includes a change in the method of measuring the outside diameter on small sizes of hose which is necessary because of difficulty in obtaining satisfactory results by the tape method with small diameters. The change in dimension for the bursting test specimen is desirable in order to provide a maximum length limit since results on long lengths may differ considerably from those obtained on short specimens making comparisons very uncertain. The changes in the immersion test procedures are intended to make these of broader general applicability when different fluids are used while still retaining reasonable standardization in the fluids recommended.

Section 4 (*b*).—Change to read as follows:

(*b*) *Outside Diameter*.—Measurement of the outside diameter of hose having an outside diameter of 1 in. or less shall be made with steel calipers graduated in increments of $\frac{1}{64}$ in. At least two readings 90 deg. apart shall be taken and averaged. Measurement of hose having an outside diameter greater than 1 in. shall be made with a tape and the outside diameter shall be determined by calculation from the measurement of the outside circumference. A tape graduated to read the diameter directly may be used.

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[5] These specifications were accepted in June as tentative but further revisions submitted subsequently to the June meeting were accepted through the Administrative Committee on Standards, see Editorial Note, p. 440.

[6] "A.S.T.M. Standards on Rubber and Rubber-Like Products," February, 1949, p. 533.

[7] 1946 Book of A.S.T.M. Standards, Part III-B.

Section 17 (a).—Add the following to the end of the first sentence: "but in no case shall the length exceed 36 in."

Section 22.—Change "solvents" to "test liquids." Also in three places, change "solvent" to "liquid."

New Section.—Add the following as a new Section 23 on Test Liquids:

23. *Test Liquids.*—The reference fuels and oils described in Paragraphs (*a*) and (*b*) shall be considered as standard immersion test media for hose, and the choice appropriate for the test shall be made from them unless other liquids are specifically required. In any case the liquid actually used shall be reported with the test results.

(*a*) *Reference Fuels.*—The standard reference fuels have been selected to include the maximum and minimum swelling effects produced by commercial gasolines. Reference Fuel No. 1 has mild action of similar order as low-swelling gasoline while Reference Fuel No. 2 has severe action exceeding that of gasolines now in service.

(*b*) *Petroleum-Base Oils.*—The standard petroleum-base lubricating oils have been selected to include low-swelling and high-swelling oils comparable in action to those commonly used in service. The aniline point of a petroleum oil appears to characterize the swelling action of that oil on synthetic rubber. In general, as the aniline point becomes lower, the swelling action of the oil becomes more severe. In oil immersion tests of hose, the high-swelling oil is usually employed.

Add at the end of the above new Section 23 (*a*) the detailed requirements for Reference Fuels Nos. 1 and 2 to read the same as given in Table II on Reference Fuels of Tentative Methods D 471 – 46 T.

Also add at the end of the above new Section 23 (*b*) the detailed requirements for Petroleum-Base Oils Nos. 1 and 3 to read the same as given in Table I of Tentative Methods D 471 – 46 T, omitting No. 2 medium swelling oil with an aniline point of 93 C.

Section 23.—Renumber as "24" and change the title of this section from "Gasoline Immersion Swelling Test" to "Swelling Test."

In Paragraph (*b*) change "gasoline" to "the test liquid" wherever it occurs in this paragraph. In two places, change "95 per cent ethyl alcohol" to "acetone." Delete the fourth sentence.

Section 24.—Renumber as "25" and change the title of this section from "Kerosine-Benzol Immersion Strength Deterioration Test" to "Strength Deterioration Test."

In Paragraph (*b*) change "solvent" to "test liquid" in the first sentence and delete "of the tube" from the second sentence.

Delete Paragraphs (*c*) and (*d*); also reletter Paragraph (*e*) as (*c*) and change to read as follows:

(*c*) ***Procedure.***—Three specimens shall be tested for tensile strength and elongation in accordance with Section 10 and the results averaged to give the properties of the rubber before immersion. The remaining three specimens shall be placed in the immersion apparatus and completely surrounded by the test liquid. With the reflux condenser in place the apparatus containing the specimens shall then be maintained at the test temperature for 48 hr. When the test liquid is a fuel, the temperature during the immersion period shall be 75 ± 5 F. (23.9 ± 2.8 C.) and when it is an oil, 200 ± 2 F. (93 ± 1 C.). Use of a thermostatically controlled liquid bath is recommended. At the end of the immersion period, the test specimens shall be removed from the immersion apparatus. If the immersion has been at elevated temperature, the specimens shall be cooled immediately in a fresh sample of the same liquid at room temperature for not less than 30 min. nor more than 60 min. but this cooling shall be omitted when the immersion is carried out at room temperature. In either case, when the test specimens are removed from the test fluid they shall immediately be dipped once in acetone and blotted lightly with filter paper to remove excess test fluid after which they shall be suspended or placed on a screen and allowed to dry at room temperature in air protected from drafts for 4 hr. The tensile strength and elongation after immersion shall be determined as before, except that the measurements for cross-sectional area and test length between bench marks shall be taken after immersion and drying. The deterioration shown by the difference between the determinations before and after immersion shall be expressed as a percentage of the original property.

Section 25.—Delete this section, renumbering the remaining sections accordingly.

Tentative Methods of Test for Compression Set of Vulcanized Rubber (**D 395-47 T**).[8]—The following change is necessary in order to provide a means for testing thin rubber materials where the standard solid specimen of the proper dimensions cannot be obtained. It is particularly needed in the automotive industry.

Section 5 (b).—In the second sentence change the number of ply specimens from "four" to "seven." Add the following sentence to the end of this paragraph: "The results obtained with specimens so prepared will not necessarily be identical with those obtained using a solid specimen of the same material having the identical state of cure."

Tentative Methods of Testing Rubber Insulated Wire and Cable (**D 470-48 T**).[9]—These revisions cover the transfer from detailed product specifications on insulated wire and cable of the methods for conducting oil-immersion and tear-resistance tests. They also provide for the adoption of an aniline point requirement to the standard immersion oil and for the addition of accelerated water absorption procedures as included in the International Power and Cable Engineers Association specifications. Several other minor changes are made which clarify the existing procedures. The committee considers that all of these changes will aid in making these tentative methods more specific and of greater utility.

Section 2.—Add the following to the end of this section: "tear resistance and effect of oil immersion."

Section 3 (a).—Change the introductory sentence to read: "Unless otherwise required by the detailed product specification, wire and cable shall be sampled as follows:"

Section 4 (a).—Add "For oil immersion . . . 3," to the list of aging tests. Add the following sentence to the end of this paragraph: "For the tear test, six individual specimens as described in Section 4 (*e*) shall be used."

Add a new Paragraph (*e*) on "specimen for the tear test" to read the same as the present Section 7 (*b*) in Tentative Specifications D 532.

Section 6.—Add a new Paragraph (*f*) to read the same as the present Section 8 (*a*), of Tentative Specifications D 532 with the exception of the last sentence which should be changed to read: "The average of the results obtained on all test specimens shall be considered as the value of the tear resistance."

New Section.—Add a new Section 8 on Oil Immersion Test, renumbering the subsequent sections accordingly, to read the same as the present Section 8 (*a*) and (*b*) of Tentative Specifications D 752, revising Paragraph (*a*) to read ". . . immersed in A.S.T.M. oil No. 2, described in Table I of the Tentative Methods of Test for Changes in Properties of Rubber and Rubber-Like Materials in Liquids (A.S.T.M. Designation: D 471), at a temperature of . . ."

Section 8.—Renumber as Section 9 and add the following to the end of this section: "except that, when the value of tear resistance from the first set of six specimens fails to conform, two additional sets shall be tested. Failure of either of the retests shall indicate nonconformity of the sample to the requirement specified."

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[8] 1947 Supplement to Book of A.S.T.M. Standards, Part III-B.

[9] 1948 Supplement to Book of A.S.T.M. Standards, Part III-B.

Section 9.—Add "and tear resistance" to Item (*a*).

Section 17.—In the first sentence, insert "single or multi conductor" between the words "completed cable."

Section 18 (*c*).—Add the following to the end of this paragraph: "Where water immersion is necessary according to Section 15 (*c*), the sample shall be immersed for a period of 1 hr. prior to voltage application.

New Sections.—Add the following two procedures for accelerated water absorption as new Sections 41, 42, 43, and 44:

ACCELERATED WATER ABSORPTION TEST

Electrical Method

41. *Test Specimen.*—(*a*) A 15-ft. test specimen of the insulated wire shall be taken after vulcanization and prior to the application of any coverings except tape applied before vulcanization. Such tape shall be removed before making the test. After not less than 48 hr. following vulcanization the specimen shall be dried for 24 hr. in air at 70 C. The specimen shall be allowed to cool in air to approximately 50 C. before immersion in water.

(*b*) *Immersion of Specimen.*—The middle 10 ft. of the test specimen shall be immersed in tap water, maintained at a temperature of 50 ± 1 C., for a period of 14 days with the 2½ ft. portion of each end kept above water as leakage insulation. A tightly fitting cover should be placed directly above the water surface with suitable water-tight bushings for the ends of the specimen. The water level should be kept constant.

(*c*) *1000 Cycle Tests.*—The capacitance of the specimen shall be measured after 1, 7, and 14 days total immersion with alternating current at a frequency of approximately 1000 cycles. The increase in capacitance from 1 to 14 days, and from 7 to 14 days shall be expressed as a percentage of the 1 and 7 day values, respectively.

(*d*) *60 Cycle Tests.*—The capacitance of the specimen shall be measured after 1, 7, and 14 days total immersion at an average stress of 80 v. per mil, 60 cycles. After 14 days total immersion the specimen power factor shall be measured at average stresses of 40 and 80 v. per mil, 60 cycles. Each value shall be given to the nearest 0.1 per cent power factor. The increase in capacitance from 1 to 14 days and from 7 to 14 days shall be expressed as a percentage of the 1 and 7 day values, respectively. The difference between the values of percentage power factor at 40 and 80 v. per mil shall be calculated after 14 days in water at 50 C.

Gravimetric Method

42. *Specimen.*—An 11-in. test specimen of the rubber-insulated conductor with all coverings removed shall be used for the test if the weight of such specimen is less than 100 g. For heavier specimens a segment 4 in. in length and 1 in. in width shall be cut from the insulation and buffed to remove all corrugations.

43. *Procedure.*—(*a*) The surface of the test specimens shall be cleaned by scrubbing with lintless cloth moistened with water and dried to constant weight in vacuum over calcium chloride at 70 ± 2 C. The sample shall be weighed to the nearest milligram, weight, *A*. The area shall be designated in square inches of a 10 in. length of the wire, or the total area in square inches of the segment, *S*. The insulated wire shall be bent in the shape of a U around a mandrel not less than three times the diameter of the specimen and the ends shall be inserted in tight-fitting holes in the cover of a 1-pt. glass jar so that 10 in. of the specimen will be submerged when the jar is completely filled with water and the cover applied.

(*b*) *Immersion of Specimens.*—The test specimen shall be immersed in freshly boiled distilled water at 70 ± 1 C. for 168 hr. and the level of the water shall be maintained flush with the under surface of the cover during the soaking period. The segment-shaped specimen should be completely submerged. The water shall be cooled to room temperature. The specimen shall be removed and the adhering water shaken off. The specimen shall be blotted lightly with lintless cloth and weighed within 3 min. to the nearest milligram, weight, *B*.

The specimen shall be dried in vacuum over calcium chloride at 70 ± 2 C. to constant weight, *C*, expressed in milligrams.

44. *Calculations.*—All results, in terms of milligrams per square inch of surface, shall be calculated as follows:

Water absorption (if C is less than A) $= \dfrac{B - C}{S}$

Water absorption (if C is greater than A) $= \dfrac{B - A}{S}$

Water soluble matter (if C is less than A) $= \dfrac{A - C}{S}$

Tentative Specifications for GR-M Polychloroprene Sheath Compound for Electrical Insulated Cords and Cables

(D 752 - 46 T).[7]—It is recommended that Section 8 on oil immersion tests be deleted as this test is being recommended for incorporation in Tentative Methods D 470.

Tentative Methods of Test for Mechanical Properties of Elastomeric Vulcanizates under Compressive or Shear Strains by the Mechanical Oscillograph (D 945 - 48 T).[9]—The following revisions are necessary in order to make the methods applicable to testing at low temperatures. This test is presently finding considerable application in low-temperature work.

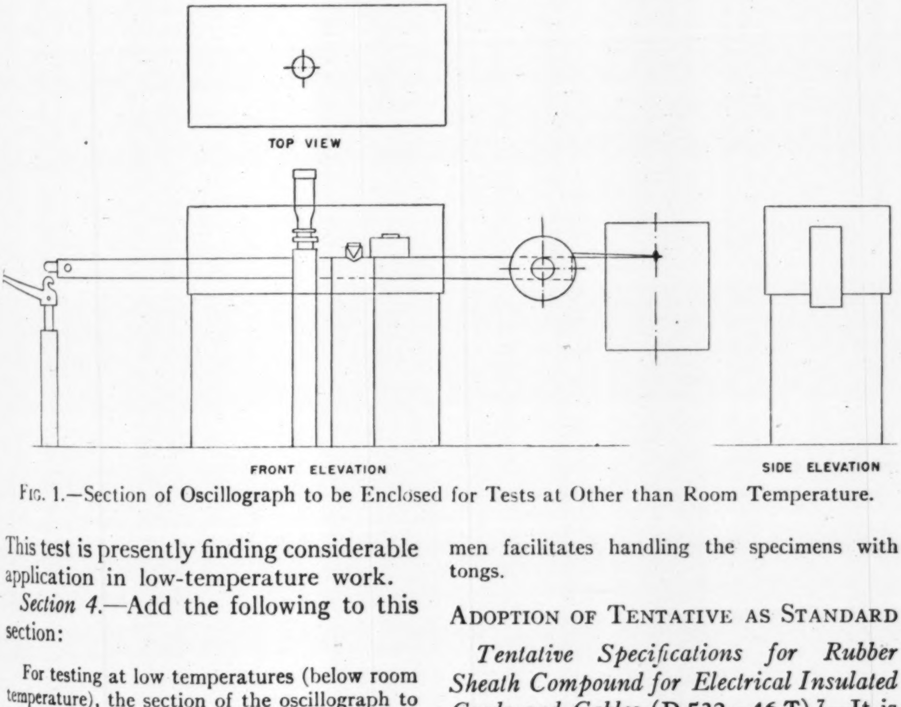

FIG. 1.—Section of Oscillograph to be Enclosed for Tests at Other than Room Temperature.

Section 4.—Add the following to this section:

For testing at low temperatures (below room temperature), the section of the oscillograph to be enclosed is shown in Fig. 3 (the accompanying Fig. 1). This enclosure shall be equipped with a shelf for storing test specimens and supplied with a circulating atmosphere at the temperature of test. Unless otherwise specified, the cold chamber and testing conditions shall conform to the conditions specified in the Tentative Recommended Practice for Conditioning of Rubber and Plastic Materials for Low-Temperature Testing (A.S.T.M. Designation: D 832). After the test specimens have been conditioned for 1 hr. at the test temperature, proceed according to the directions given in Section 5.

NOTE.—The test specimen shall be attached to the No. 400 grit A sandpaper by means of an adhesive. This facilitates handling the specimens with tongs.

Section 7.—Make the same addition to this section as given above for Section 4, except that the reference shall be to Section 8 at the end and the note shall read as follows:

NOTE.—The test specimens shall be attached to the metal end plates by means of an adhesive. A set of end plates attached to each test specimen facilitates handling the specimens with tongs.

ADOPTION OF TENTATIVE AS STANDARD

Tentative Specifications for Rubber Sheath Compound for Electrical Insulated Cords and Cables (D 532 - 46 T).[7]—It is proposed to revise these specifications by deletion of Section 7 (*b*) and Section 8 on tear test, and the revised specification is recommended for reference to letter ballot of the Society for adoption as standard. This revision removes the tear test procedure which will no longer be necessary after approval of the presently proposed revision of Methods D 470. The specifications themselves have been in use for several years without criticism or comment.

Adoption of Tentative Revision as Standard

Standard Method of Test for Indentation of Rubber by Means of the Pusey and Jones Plastometer (**D 531 – 41**).[7]—The tentative revision[9] of Section 5 (*a*) of this standard which was submitted in January, 1948, clarifies the choice of indentor points when testing rubber compounds of different hardnesses and makes the procedure for soft compounds more specific. No objections have been received since the publication of the tentative revision and it is therefore proposed to incorporate it in the standard.

Revisions of Standards, Immediate Adoption

The Committee recommends for immediate adoption the following revisions in three standards, and accordingly requests the necessary nine-tenths affirmative vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society:

Standard Specifications for Cotton Rubber-Lined Fire Hose for Public and Private Fire Department Use (**D 296 – 38**).[7]—These specifications have been thoroughly revised, as appended hereto,[10] to bring them into agreement with the current specifications of the Underwriters Laboratories, Inc. The new specifications reflect the influences of many of the war-time experiences in the manufacture of this hose and bring the standard in line with current manufacturing practice. Immediate adoption is requested because the present specifications are obsolete and are not being used.

Standard Method of Testing Compressed Asbestos Sheet Packing (**D 733 – 46**).[7]—The following revision adds details for conducting a compressibility test after immersion. This test is in use and the standardized procedure is needed at once.

Section 10 (*b*).—Insert the following sentence between the first and second sentences: "Specimens for compressibility after immersion shall be similar to those employed for weight and thickness change." Add the following sentence to the end of the paragraph: "The calculation of compressibility shall be based upon the original rather than the swelled thickness."

Standard Specifications for GR-M Polychloroprene Sheath Compound for Electrical Insulated Cords and Cables Where Extreme Abrasion Resistance is not Required (**D 753 – 47**).[8]—The change in wording of the oil immersion requirement in Section 4 expresses the requirement in the same terms as presently used in Specifications D 752. The procedure for the oil immersion test is not necessary in these specifications after the adoption of the currently proposed revisions in Methods D 470. Since these changes involve no change in substance but merely bring the specimens in line with the other standards, it is believed that they should be adopted immediately.

Section 4.—Change the oil immersion test requirement to read as follows: "Tensile strength and elongation at rupture after 18 hr. in oil immersion test at 249 to 251 F. (120.6 to 121.7 C.), min., per cent of the original value . . . 60."

Section 8.—Delete this section on oil immersion test.

Revision of Standard and Reversion to Tentative

Standard Methods of Dynamic Testing for Ply Separation and Cracking of Rubber Products (**D 430 – 40**).[7]—The following revision merely corrects an error in the description of the construction of the Scott Flexing Machine. Subcommittee XVIII, however, is working on an extensive revision of this standard and expects in the near future to recommend numerous changes. It is believed therefore that the standard should be reverted to the tentative status.

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[10] These revised specifications were accepted by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 6.

Section 9.—Substitute the following for the present second sentence: "Each hub rotates on a double row, radial type, ball bearing of the grease-sealed type with double shields."

WITHDRAWAL OF TENTATIVE

Tentative Method of Test for Low-Temperature Brittleness of Rubber and Rubber-Like Materials (**D 736 – 46 T**).[7]—This method which is known as the Thiokol bent loop test has never been considered to have adequate precision but was originally published as the most convenient method available at the time. Subsequent experience with other methods has indicated that the Tentative Method of Test for Brittle Temperature of Plastics and Elastomers (D 746 – 44 T) is superior and the committee now feels that Method D 736 does not have adequate precision to justify its continuance. It is accordingly recommended that Method D 736 be withdrawn and that in all specification work requiring the brittleness test, it be replaced by Method D 746.

EDITORIAL CHANGE IN METHOD

Tentative Methods of Test for Changes in Properties of Rubber and Rubber-Like Materials in Liquids (**D 471 – 46 T**).[7]—The committee recommends that footnote 3 referred to in Table I be revised editorially by eliminating the words "as Sun XX Heavy Cable." The Sun Oil Co. has advised that the subject oil will be furnished in the future as A.S.T.M. Oil No. 2 rather than under its own commercial brand.

CONTINUATION OF TENTATIVES WITHOUT REVISION

The committee recommends that all tentatives under its jurisdiction other than those referred to in this report be continued as tentative. Work is under way on revision of a number of these but their adoption as standard must be deferred until this is completed.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[11]

ACTIVITIES OF SUBCOMMITTEES

As in the previous year, all of the subcommittees of Committee D-11 have been very active and considerable reorganization has been in progress. This has been reflected in a number of changes in subcommittee chairmen due to resignation of the former chairmen. The loyal service of the retiring chairmen and the cooperation of the new appointees is greatly appreciated by the committee. The following changes have occurred: M. G. Schoch replaced C. H. Zieme as chairman of Subcommittee II on Belting. W. P. Tyler became chairman of Subcommittee XI on Chemical Analysis replacing S. Collier. R. H. Taylor accepted the chairmanship of Subcommittee XXVI on Processibility Tests formerly held by V. L. Smithers. In making this change, Mr. Taylor resigned as chairman of Subcommittee XIV and Mr. R. F. Tener was appointed chairman of this Subcommittee on Abrasion Tests. In the Technical Committee on Automotive Rubber, Messrs. J. L. McCloud, chairman, and G. H. Swart, secretary, retired. S. R. Doner was elected as the new chairman and was replaced in his former office of vice-chairman by H. A. Winkelman. W. B. Davies was elected as the new secretary.

Organization of a new Subcommittee on the Application of Statistical Quality

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[11] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

Control Methods to Rubber Products was authorized. This subcommittee, however, is still in process of organization.

Substantial progress is being made in a wide variety of projects in most of the established subcommittees. Results of their work will be presented in the form of definite recommendations as the projects are completed since detailed consideration of these numerous activities is beyond the scope of this report.

This report has been submitted to letter ballot of the committee, which consists of 194 members; 118 members returned their ballots, of whom 103 have voted affirmatively and 1 negatively.

Respectfully submitted on behalf of the committee,

SIMON COLLIER,
Chairman.

ARTHUR W. CARPENTER,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-11 presented to the Society through the Administrative Committee on Standards the following recommendations:

New Tentative Specifications and Methods of Test for:

Concentrated, Ammonia Preserved, Creamed and Centrifuged Natural Rubber Latex (D 1076-49 T).

New Tentative Methods of:

Test for Determining the Curing Characteristics of Vulcanizable Mixtures During Heating by Means of the Shearing Disk Viscometer (D 1077 - 49 T), and
Test for Evaluating Pressure Sealing Properties of Rubber and Rubber-Like Materials (D 1081 - 49T).

Revision of Tentative Specifications and Methods of Test for:

Latex Foam Rubbers (D 1055 - 49 T), and
Sponge and Expanded Cellular Rubber Products (D 1056 - 49 T).

Revision of Tentative Methods of:

Test for Compression Set of Vulcanized Rubber (D 395 - 47 T),
Test for Changes in Properties of Rubber and Rubber-Like Materials in Liquids (D 471 - 46 T),
Testing Asphalt Composition Battery Containers (D 639 - 46 T),
Test for Indentation of Rubber by Means of a Durometer (D 676 - 47 T), and
Test for Viscosity of Rubber and Rubber-Like Materials by the Shearing Disk Viscometer (D 927 - 47 T).

Tentative Revision of Standard Methods of:

Testing Compressed Asbestos Sheet Packing (D 733 - 46).

These recommendations were accepted by the Standards Committee on December 22, 1949, and the new and revised tentatives together with the tentative revision of Standard Methods D 733 - 46 appear in the 1949 Book of A.S.T.M. Standards, Part 6.

On January 17, 1950, the Administrative Committee on Standards accepted the recommendation of Committee D-11 that the Standard Methods of Tension Testing of Vulcanized Rubber (D 412-41) be revised and reverted to tentative. The new tentative methods appear in the 1949 Book of A.S.T.M. Standards, Part 6.

REPORT OF COMMITTEE D-12
ON
SOAPS AND OTHER DETERGENTS*

The annual meeting of Committee D-12 on Soaps and Other Detergents was held in New York, N. Y., on March 22 and 23, 1949. In addition to the recommendations given below, an important feature of this meeting was a round-table discussion of standard soiled cloths and their use in evaluation of detergents.

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends that the Standard Methods of Sampling and Chemical Analysis of Alkaline Detergents (D 501 - 46) be revised as follows and asks for a nine-tenths affirmative vote at the Annual Meeting in order that these revisions may be referred to letter ballot of the Society for immediate adoption:

Sections 8 and 9.—Change to read as follows:

8. *Matter Volatile at 150 C. to 155 C.*—Place approximately 2 g. of the sample in a tared weighing bottle and weigh to the nearest 0.1 mg. Remove the stopper and dry in an oven at 150 C. to 155 C. for 1 hr. Replace the stopper and allow to cool to room temperature in a desiccator containing no desiccant and reweigh. Calculate the percentage of volatile matter as follows:

$$\text{Volatile matter, per cent} = \frac{\text{loss in weight} \times 100}{\text{weight of sample}}$$

9. *Total Alkalinity as Na_2CO_3.*—In a closed bottle weigh out to the nearest 0.1 mg. approximately 1.2 g. of the sample. Dissolve in about 50 ml. of distilled water in a 400-ml. beaker and add 2 drops of a 0.1 per cent solution of methyl orange indicator. Run in, while stirring, 0.5 *N* HCl solution until one drop establishes the first appearance of a pink color in the solution. Remove the beaker, heat to boiling, and boil for 1 min. to remove most of the CO_2. Cool and finish the titration to the first appearance of a pink color in the solution. Calculate the total alkalinity as follows:

$$\text{Total alkalinity, per cent} = \frac{\text{ml. of HCl} \times \text{normality} \times 5.3}{\text{weight of sample}}$$

Section 10.—Change the first part of the first sentence to read: "Weigh 8.4 g. of the sample to the nearest 0.05 g."

Add the following note to this section:

NOTE.—For referee purposes, or when more accurate results are required than are yielded by the procedure described in Section 10, the method described in Section 11 shall be used.

New Section.—Add the following as a new Section 11, renumbering the subsequent sections accordingly:

11. *Sodium Bicarbonate by Potentiometric Titration.*—Weigh approximately 10 g. of the sample to the nearest milligram. Transfer to a 250-ml. volumetric flask and dissolve in freshly boiled, cooled distilled water. Dilute to the mark, mix thoroughly, and transfer, by means of a pipet, a 50-ml. aliquot of the solution to a 250-ml. beaker. Add exactly 5.0 ml. of a 0.1 *N* sodium hydroxide solution from a pipet or buret; then add 50 ml. of 1.0 *N* barium chloride solution which has been previously adjusted to neutrality to phenolphthalein. Introduce the electrodes of a glass-electrode pH meter (Note 1) and mix continuously by means of a mechanical stirrer. Titrate with 0.1 *N* HCl solution without undue delay, in order to minimize absorption of CO_2 from the atmosphere. When the pH begins to change, record the readings at intervals of 0.1 ml. of HCl. In an identical manner carry out a blank determination (Note 2) on 10 g. of bicarbonate-free sodium carbonate prepared by igniting another portion of the same sample overnight at 200 C. Plot the pH

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* Presented at the Fifty-second Annual Meeting of the Society, June, 27–July 1, 1949.

values *versus* volume of 0.1 N HCl solution for both the sample and the blank on the same paper. The volume of HCl represented by the difference between the points of inflection of the two curves is equivalent to the sodium bicarbonate content of the sample. Calculate the results as follows:

$$\text{NaHCO}_3\text{, per cent} = \frac{(\text{ml. of HCl for blank} - \text{ml. of HCl for sample}) \times \text{normality} \times 8.4}{\text{wt. of sample in aliquot}}$$

NOTE 1.—Careful standardization of the pH meter with standard buffers is not necessary. Instruments as specified in the Tentative Method for Determination of the pH of Aqueous Solutions with the Glass Electrode (A.S.T.M. Designation: E 70) are satisfactory.

NOTE 2.—The blank correction is required since appreciable amounts of sodium hydroxide are occluded in the precipitated barium carbonate. It is imperative that identical quantities of sodium hydroxide be used for both sample and blank, since the blank correction is related directly but not linearly to the quantity of excess sodium hydroxide present when the barium carbonate is precipitated. The correction varies sufficiently with different reagents so that it should be measured for each determination unless its constancy has been established.

Section 11.—Renumber as Section 12 and change the first two sentences to read as follows by the addition of the italicized words:

12. Dissolve 20 g. of the sample *weighed to the nearest 0.1 g.* in 300 ml. of distilled water in a 400-ml. beaker. Filter through a previously prepared dried and weighed Gooch *or fritted glass* crucible.

New Sections.—Add the procedures for sampling and analysis of borax now appearing in Tentative Method D 501 - 48 T, which is being recommended for adoption as standard.

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the Tentative Method of Total Immersion Corrosion Test of Water-Soluble Aluminum Cleaners (D 930 - 47 T) be approved for reference to letter ballot of the Society for adoption as standard, with the following revisions:

Section 2 (b).—Change to read as follows: "(*b*) *Condensers.*—Allihn or other type condensers having a jacket not less than 200 mm. in length."

Section 4 (a).—Delete the last sentence in this paragraph.

Section 5.—In the first sentence of Paragraph (*a*) change "when using" to read "with."

In Item (*1*) of Paragraph (*b*) change the second sentence to read as follows: "If the cleaner is not soluble to the extent noted in the stock solutions indicated, a weighed quantity of the cleaner shall be transferred to a graduate and made up to volume. The undissolved portion of the cleaner is to be transferred to test tubes by rinsing with the supernatant liquid."

In Paragraph (*d*) add the following sentence to the end of the paragraph: "In any case the top temperature will not exceed the boiling point."

Section 6 (d).—Change Item (*5*) to read as follows: "Immerse the strips, including blanks, in a beaker of nitric acid (sp. gr. 1.42), heating if necessary, to remove accretions."

Section 7 (a).—Change the second sentence to read as follows: "Attach the tube containing the specimen to a reflux condenser and maintain at the temperature specified in Section 5 (*d*)."

The committee also recommends that the Tentative Method of Sampling and Chemical Analysis of Borax (D 501 - 48 T) be approved for reference to letter ballot of the Society for adoption as standard and that it be incorporated in Standard Methods D 501.

CONTINUATION OF TENTATIVES

The committee recommends that the Tentative Specifications for Sodium Bicarbonate (D 928 - 47 T) be continued as tentative, without revision, pending completion of analytical methods.

The committee also recommends that the Tentative Specifications for Borax (D 929 - 47 T) be continued as tentative with an editorial change consisting of the deletion of the second sentence in Section 2.

Editorial Changes in Standards

In order that the Federal and A.S.T.M standards may agree, the committee recommends that the sentence in the section on "Basis of Purchase" which reads: "In the event that the calculation under Paragraph (*d*) results in a figure greater than 100 per cent, due to low moisture content at the time of filling, weighing and packing, the seller waives the right to invoice the purchaser for any amount in excess of 100 per cent," be deleted from the following thirteen standards:

D 455 - 48
D 496 - 48
D 497 - 48
D 498 - 48
D 499 - 48
D 533 - 44
D 535 - 48
D 536 - 48
D 592 - 48
D 593 - 48
D 630 - 48
D 690 - 48
D 691 - 44

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[1]

Activities of Subcommittees

Subcommittee T-1 on Soaps (L. K. Whyte, chairman, E. W. Blank, acting) reported that the joint A.S.T.M.-American Oil Chemists' Society Committee is continuing cooperative work on the determination of borax in soap and in sulfonated detergent mixtures.

Subcommittee T-3 on Dry Cleaning (G. P. Fulton, chairman) will make a cooperative effort to evaluate several different methods of moisture determination. A proposed specification for dry-cleaning solvent was discussed and is to be revised.

Subcommittee T-4 on Special Detergents (W. H. Koch, chairman) recommended the adoption as standard of Tentative Method D 501 - 48 T and certain changes in the procedure for analysis of soda ash in Standard Methods D 501 - 46.

Subcommittee T-5 on Physical Testing (J. A. Woodhead, chairman).—A task group headed by J. K. Petry reported on cooperative tests made in evaluation of the canvas disk method. Unsatisfactory variation in test results was experienced, and a further effort to trace the variables will be made, including a study of the Draves method.

A proposed draft of a method for lather evaluation (the Ross-Miles test) was reported by C. A. Cohen. Cooperative tests are to be made and the test will then be offered as a proposed method if found acceptable.

A "Proposed Method for the Determination of pH of Aqueous Solutions of Soaps and Detergents" was presented by H. R. Suter as task group chairman. Work will be continued on this method.

A report of cooperative testing of the Terg-O-Tometer, which is intended to simulate on a small scale the washing action of domestic washing machines, was made by J. A. Woodhead. Reproducibility of results was obtained with one soil and one detergent by the cooperating laboratories.

Subcommittee T-6 on Metal Cleaning (J. C. Harris, chairman) recommended adoption as standard of Tentative Method D 930 - 47 T with the revisions mentioned earlier in this report.

A method for corrosion test with metals other than aluminum was presented by R. A. Ehrhardt. Discussion of the method resulted in a suggestion that this be resubmitted on the basis of four general types of cleaners: electrolytic, nonelectrolytic aqueous, emulsion-solvent, and solvent for spray or vapor cleaning.

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[1] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

Discussion of a method for measurement of surface tension developed weaknesses in the original form, which are to be corrected and resubmitted for subcommittee approval.

Two papers were presented at the meeting, one on "Apparatus for the Performance Testing of Emulsion Cleaners," by F. L. Chase of the Frigidaire Corp., and the other on "Application of the Radioactive Tracer Technique in Metal Cleaning," by J. C. Harris, R. E. Kamp, and W. H. Yanko of Monsanto Chemical Co.[2]

Subcommittee S-1 on Soaps (F. Krassner, chairman).—Discussion of proposed specifications for low-temperature washing by (*a*) chipped or granular soap and (*b*) solid soap revealed points of difference between A.S.T.M. proposed specifications and Federal specifications. The controversial points are centered about inclusion of sodium silicate as a preservative, use of an organic inhibiting agent, and a maximum content of copper. Attempts will be made to reconcile these variations through close cooperation between the producers, the Federal Specification Board's Technical Committee on Detergents, and the A.S.T.M.

Subcommittee G-3 on Papers and Publications (W. H. Koch, chairman) reported that the Bibliography on Metal Cleaning had become of sufficient size that it warranted separate publication. J. C. Harris has accordingly completely revised, enlarged, and cross indexed this bibliography. This bibliography will be available shortly.

Subcommittee G-4 on Membership (J. N. Borglin, chairman) reported a successful drive to maintain the consumer, producer, and general interest balance of the committee.

C. A. Cohen was appointed as representative of Committee D-12 on the Task Group on Distillation Tests of Committee E-1 on Methods of Testing.

This report has been submitted to letter ballot of the committee, which consists of 102 members; 83 members returned their ballots, of whom 76 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

F. W. SMITHER,
Chairman.

J. C. Harris,
Secretary.

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[2] ASTM BULLETIN, No. 158 May, 1949, p. 49(TP 75).

REPORT OF COMMITTEE D-13
ON
TEXTILE MATERIALS*

Committee D-13 on Textile Materials held two 3-day meetings during the year. The fall meeting was in Washington, D. C., on October 13 to 15, 1948, in conjunction with a meeting of the Washington District Council, and there was a registered attendance of 177 members and guests; the spring meeting was in New York, N. Y., on March 16 to 18, 1949, with a total attendance of 225. Sixteen subcommittees and sections held sessions at both the fall and the spring meetings. Administrative guidance of the committee required two meetings of the Advisory Committee and two of the Officers Committee.

The papers presented at the fall meeting consisted chiefly of reports from delegates on the accomplishments at international meetings dealing with textile standardization [1] Concerning Textile Committee 38 of the International Organization for Standardization (I.S O.) which met at Buxton, England, June 7 to 12, 1948, H. J. Ball reported on the general proceedings and on the tension testing of fabrics; G. S. Buck, Jr., covered the recommendations dealing with standard atmospheric conditions for testing; A. G. Scroggie presented the subjects of universal yarn numbering systems, of definition of rayon, and of a generic term for man-made fibers; J. B. Goldberg discussed the status of the secretariat of Textile Committee 38. The meeting of the International Wool Textile Organization, held at Amsterdam, Holland, was described by J. I. Hardy, and textile research and standardizing activities in many European countries was reported upon by W. D. Appel. The final paper[2] was on the subject of "Testing and the Federal Trade Commission," presented by Henry Miller, a member of the Federal Trade Commission.

The theme of the Papers Session at the spring meeting was the use of X-rays in textile testing. The following papers[3] of an educational character were presented: "The Application of X-Ray Technique in Textile Testing with Particular Attention to the Natural Cellulosic Fibers," by W. A. Sisson, American Viscose Corp.; "The Application of X-Rays in the Study of Synthetic Fibers," by A. F. Smith, E. I. du Pont de Nemours and Co.; and "X-Ray Study of Wool and Other Protein Fibers," by G. C. Nutting, U. S. Department of Agriculture.

One change was made in the organization of Committee D-13 during the year. Subcommittee B-6 on Significance of Tests were placed in the C group with the designation C-5, but the membership was reorganized to consist only of the chairmen of all A subcommittees and of Subcommittee B-1. Julian S. Jacobs was appointed as chairman, vice R. H. Brown and Dean Harvey.

The following changes in subcommittee and section chairmanships have oc-

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[*] Presented at the Fifty-second Annual Meeting of the Society, June 27-July 1, 1949.

[1] ASTM BULLETIN, No. 156, January, 1949, p. 18.

[2] ASTM BULLETIN, No 157, March, 1949, p. 22.

[3] These papers are published in A.S.T.M. Standards on Textile Materials, October, 1949. (Issued as a separate publication.)

curred and were approved by the Advisory Committee at the spring meeting: J. K. Frederick, Jr., vice J. B. Goldberg, as chairman of Subcommittee A-2, Section I; Werner von Bergen, vice A. G. Ashcroft, as chairman of Subcommittee A-3; O. P. Beckwith, vice Werner von Bergen, as chairman of Subcommittee A-3, Section I; H. R. Anderson, vice Fred Noechel, as chairman of Subcommittee A-3, Section III; W. K. Lydic, vice R. F. Caroselli, as chairman of Subcommittee A-8, Section VI; John Hintermaier, vice O. P. Beckwith, as chairman of Subcommittee B-5.

In recognition of the numerous and significant contributions made by the late Dr. Harold DeWitt Smith to the science of utilization of textile fibers and to give further momentum to the engineering approach to the properties and uses of textile fibers, as was so ably presented in his Edgar Marburg Lecture given before the Society in June, 1944, a Harold DeWitt Smith Memorial Medal is to be awarded annually by Committee D-13 for outstanding achievement along such lines. This testimonial to Dr. Smith, and to his lifetime of devotion to the cause of fundamental textile research, has been made possible through the generosity of the Fabric Research Laboratories, Inc. Regulations governing the award and its financing have been agreed upon by Committee D-13 and the Fabric Research Laboratories, Inc., and approved by the Board of Directors of the A.S.T.M. The personnel of the first Committee of Award is composed of the following members of Committee D-13; H. J. Ball, chairman, A. G. Ashcroft, K. L. Hertel, G. H. Hotte, and A. G. Scroggie. W. H. Whitcomb will serve as secretary of the award committee.

The Subcommittee on Fibers and Fabrics of the Committee on Quartermaster Problems of the National Research Council has requested the assistance of Committee D-13 in the formation of a liaison committee to revise the sampling provisions contained in both the Federal and the Armed Forces specifications relating to textiles. Due to the type of problem involved and in view of the work on sampling procedures which has already been accomplished in Subcommittee B-5 on Sampling, Presentation and Interpretation of Data, O. P. Beckwith, its chairman, was recommended. The recommendation was accepted, and he is now serving as chairman of the task group which has been set up to handle the revision.

There has been completed during the year an extensive set of Recommendations on the Form of A.S.T.M. Methods of Test for Textiles which represents the conscientious effort of A. G. Scroggie and O. P. Beckwith. These recommendations have been reviewed and approved by the Advisory Committee and have been promulgated as a guide to members of Committee D-13 who have to do with the preparation or revision of methods of test for textiles in the future. Their use will result not only in a greater degree of editorial uniformity but will tend to provide against inadequacies and pitfalls in the standards against which only extensive experience can forewarn.

The Advisory Committee has approved the appointment of Lewis Larrick to represent Committee D-13 on Committee E-7 on Radiographic Testing and on the Section on Calibration of Testing Machines and Apparatus of Committee E-1 on Methods of Testing, vice W. D. Appel.

RECOMMENDATIONS AFFECTING STANDARDS

Committee D-13 is presenting for publication five new tentatives and is recommending the revision of eight tentatives, tentative revisions of two standards, adoption as standard of several definitions, three tentatives, and the tentative revisions of three standards, revisions for immediate adoption as standard of eight standards, and the withdrawal of one standard and three tentatives. The committee is also recommending the reaffirmation of eleven standards.

The standards and tentatives affected, together with the revisions recommended, are given in detail in Appendix I.

All tentatives not specifically referred to are being actively studied by the respective sponsoring committees.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

Activities of Subcommittees

Besides the activities indicated by the recommendations appearing in Appendix I, the following should be mentioned:

Subcommittee A-1 on Cotton and Its Products (B. L. Whittier, chairman):

Section I on Cotton (R. L. Lee, Jr., chairman) is undertaking a study of methods for evaluating fineness.

Section II on Cotton Yarns and Threads (W. R. Marsden, chairman) is planning a thorough review of the Standard Methods of Testing and Tolerances for Cotton Sewing Thread (D 204 – 42).

Subcommittee A-2 on Man-Made Organic Base Fibers and Their Products (A. M. Tenney, chairman):

Section I on Filaments, Monofilaments, and Filament Yarns (J. B. Goldberg, chairman) is developing methods of testing fibers and yarns made up of fibers other than rayon and estron.

Section II on Fabrics (G. H. Hotte, chairman) is engaged in a study of fabric distortion.

Subcommittee A-3 on Wool and Its Products (A. G. Ashcroft, Chairman):

Section I on Wool (Werner von Bergen, chairman) is continuing its survey on wool testing and studies of raw wool shrinkage, determination of moisture, yield of tops, noils, and wastes, and fineness of wool tops. Methods for the determination of vegetable matter and ash in wool are being studied.

Subcommittee A-5 on Bast and Leaf Fibers and Their Products (S. J. Hayes, chairman) is continuing its studies on knot breaking strength and test methods for twine.

Subcommittee A-6 on Household and Garment Fabrics (Laura E. Pratt, chairman) is developing methods of test for blankets, and serviceability tests on bleached wide cotton sheeting.

Subcommittee A-9 on Tire Cord and Fabrics (F. C. Kennedy, chairman) is working on revisions and consolidation of the Tests and Tolerances for Cotton Tire Cord (D 179 – 46 T) and for Rayon Tire Cord (D 885 – 46 T).

Subcommittee A-10 on Felt (W. H. Lehmberg, chairman) is discontinuing its study of the dumb-bell shaped tension specimens because its use would be of limited value. The studies of stiffness testers and sheet felt specifications are being continued.

Subcommittee A-12 on Hosiery (E. N. Ditton, chairman) is presenting its first method in the form of a Tentative Method of Test for Stretch of Hosiery, as appended to this report.[5] A method of test for snag resistance is being developed.

Subcommittee A-14 on Bonded Fabrics (G. B. Harvey, chairman) is studying methods of test for weight, tensile and bursting strengths, tearing resistance, dry cleaning and laundering, fire retardency, air permeability, and water absorbency.

Subcommittee B-1 Methods (W. D. Appel, chairman) has under investigation different types of abrasion testers, shrinkage of knit fabrics, field tests for performance, elastic fabrics, stress-strain curves, fraying of fabrics, crease resistance, determination of small amounts of copper and manganese in textiles, fluidity of cellulose dispersions, and water repellency.

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[4] The letter ballot vote on these recommendations was favorable the results of the vote are on record at A.S.T.M. Headquarters.

[5] This method was accepted as tentative by the Society and appears in the 1949 Book of A.S.T.M. Standards, Part 5.

Subcommittee B-2 on Nomenclature and Definitions (A. G. Scroggie, chairman) has under consideration a number of new definitions and is also studying certain definitions with a view to bringing about better agreement between A.S.T.M. and definitions under consideration in the I.S.O. Committee 38.

Subcommittee B-3 on Atmospheric Conditions and Regain (R. H. Brown, chairman) is studying the conflicts between A.S.T.M. humidity definitions and those proposed in I.S.O. Committee 38, drying ovens, methods of preconditioning test specimens, rate of conditioning of specimens in standard atmosphere, moisture regain tables for textile materials exposed to various temperatures and relative humidities, instruments for indicating and recording relative humidity, and for measuring moisture regain, and determination of weight per yard of conditioned fabrics.

This report has been submitted to letter ballot of the committee, which consists of 345 members; 148 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

H. J. BALL,
Chairman.

W. H. WHITCOMB,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-13 presented to the Society through the Administrative Committee on Standards a tentative revision of the Standard Method of Test for Hard Scoured Wool in Wool in the Grease (D 584 - 47). This tentative revision was accepted by the Standards Committee on September 22, 1949, and appears in the 1949 Book of A.S.T.M. Standards, Part 5.

APPENDIX

RECOMMENDATIONS AFFECTING STANDARDS ON TEXTILE MATERIALS

In this Appendix are given proposed revisions in certain standards and tentatives covering textile materials, which are referred to earlier in this report. These standards and tentatives appear in their present form in the 1946 Book of A.S.T.M. Standards, Part III-A, or in the 1947 and 1948 Supplements to Book of A.S.T.M. Standards, Part III-A.

New Tentatives

Committee D-13 recommends that the following six new methods be accepted for publication as tentative as appended hereto.[1]

Tentative Methods of Core Sampling of Wool in Packages for Determination of Percentage of Hard Scoured Wool Content, prepared by Subcommittee A-3,

Tentative Specifications and Methods of Testing Asbestos Lap, prepared by Subcommittee A-4,

Tentative Methods of Testing Single Kraft Yarn, prepared by Subcommittee A-11,

Tentative Method of Test for Stretch of Hosiery, prepared by Subcommittee A-12, and

Tentative Method of Test for Yarn Number of Yarn from Fabrics, prepared by Subcommittee B-1.

Revisions of Tentatives

Tentative Methods of Testing and Tolerances for Cotton Yarns (D 180 - 47 T):

Revisions in these methods prepared by Section II of Subcommittee A-1 are recommended as appended hereto.[2]

Tentative General Methods of Testing Cotton Fibers (D 414 - 47 T):

Section I of Subcommittee A-1 prepared the revision of these methods as appended hereto[2] which covers the addition of an alternate method for determining length of cotton fibers by means of the fibrograph.

Tentative Methods of Testing and Tolerances for Glass Yarn (D 578 - 47 T):

Revisions in these methods prepared by Subcommittee A-8 are recommended as appended hereto.[2]

Tentative Methods of Test for Resistance of Textile Fabrics and Yarns to Insect Pests (D 582 - 45 T):

Subcommittee B-1 submitted the revised methods appended hereto,[2] which are recommended by Committee D-13.

Tentative Methods of Test for Evaluating Compounds Designed to Increase Resistance of Fabrics and Yarns to Insect Pests (D 627 - 41 T):

The following revision of the procedure for washing treated specimens was prepared by Subcommittee B-1:

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[1] These methods and specifications were accepted as tentative by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 5.

[2] These revised methods and specifications were accepted by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 5.

Section 5.—Change to read as follows:

5. *Washing.*—(*a*) The treated specimen shall be washed in accordance with the following procedure and repeated up to five times, as desired.

Wash the specimen by hand (squeezing suds through fabric) for 5 min. at 100 ± 5 F. in a soap solution containing 0.2 per cent neutral chip soap,[a] using a bath of such length that it contains 30 times as much water as fabric (Note). Rinse the specimen twice in water at approximately 85 F. (29.4 C.) using the same dilution of water as in the washing, that is, 30 to 1.

NOTE.—This method of washing woolens more closely corresponds with methods employed in actual use conditions than the colorfastness wash tests described in the Standard Method of Test for Colorfastness of Dyed or Printed Wool, Silk, Rayon or Estron Fabrics to Laundering or Domestic Washing (A.S.T.M. Designation: D 436).

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[a] This grade of soap is described in "Colorfastness of Wool Textiles," *Technical Manual and Year Book*, Am. Assn. of Textile Chemists and Colorists, Vol. XXIV, Part III, p. 108 (1947-1948).

Tentative Recommended Practice for Planning Interlaboratory Testing of Textile Materials (D 990 - 48 T):

The following revisions, prepared by Subcommittee B-5, are recommended by Committee D-13:

Section 3.—Make the following revisions in this section:

In Step D, revise Item (*1*) to read: "Only operators who are average or above average in skill in the particular field shall be used. The choice of operator skill level should be decided after committee discussion."

Table I.—In the note under this table, after "Sample 1, a part of the material," add the following: "Sample 2, 3, etc., other parts of the same material."

In Step G, Item (*3*) under Calculations, replace "as revised in 1943" with "latest revision."

In Equation 1 under Average Range, replace parentheses with vertical bars.

In the paragraph following this formula, transpose the reference to footnote 5 from "size" to "d_2."

Insert the following new Equation 5, renumber the present Equation 5 as 6 and change other references accordingly:

Alternate Equation for Standard Deviation:

This equation may be used for the special case of two data per subgroup:

σ_i calculated standard deviation

$$= \sqrt{\sum_{i=1}^{N_s} \frac{(T_{2i} - T_{1.})^2}{2N_s}} \quad \text{..(5)}$$

Change the first paragraph after the legend for Equation 4 to read as follows:

With N so calculated it will be correct in 90 cases out of 100 (when $t = 1.65$) to state that the average of N tests will be within E per cent of the true average for the material.

Appendix.—Make the following changes in the Appendix:

In Alternate Method on Material A of Example 1, change Equation "6" to "5," and transpose the exponent "2" outside the parentheses.

In Alternate Method on Material B, change Equation "6" to "5," and Equation "5" to "6." Also change the answer in the latter equation from "4.0" to "4.1."

In the same method, change Equation 4 to read as follows:

$$v = \frac{1.88 \times 100}{30.72} = 6.1 \text{ per cent}$$

In Alternate Method on Material A of Example 2, change Equation "6" to "5." Make the same change in the Alternate Method of Material B.

Tentative Definitions of Terms Relating to Textile Materials (D 123 - 48 T):

The following revisions, prepared by Subcommittee B-2, are recommended by Committee D-13.

Revise the definitions for sley, and monofilament, textile to read as follows, and add the following new definitions for porosity, permeability, and moisture equilibrium for testing:

Sley, n.—The number of ends per inch of warp exclusive of the selvage.

NOTE 1.—The point at which the sley is measured must be specified, for example the reed, the gray cloth on the loom, the gray cloth off the loom, or the finished cloth.

NOTE 2.—In the United Kingdom "sley" refers to part of the loom and is not used as a measure of cloth construction.

Monofilament, n.—(*a*) A single filament,

(*b*) A single filament of sufficient size to function as a yarn in normal textile operations.

Porosity, n.—The ratio of the volume of air or void contained within the boundaries of a material to the total volume (solid matter plus air or void) expressed as a percentage. Porosity accordingly equals:

$$\frac{V_v \times 100}{V_t}$$

where: V_v = volume of voids, and V_t = total volume.

Permeability, n.—The rate of flow of fluid under a differential pressure through a material.

NOTE 1.—Fluid under differential pressure means:

(*1*) Gas under differential gas pressure,

(*2*) Vapor under differential vapor pressure, and

(*3*) Water under differential hydrostatic pressure.

Moisture Equilibrium for Testing, n.—The equilibrium moisture condition reached by a sample after free exposure to moving air controlled at standard conditions when the increase in weight of the sample does not exceed a prescribed rate. For test purposes moisture equilibrium must be reached by absorption from a lower regain.

NOTE 1.—In the absence of a specified rate, an increase of less than 0.1 per cent of the sample weight after a 2-hr. exposure is considered satisfactory.

NOTE 2.—For tests to be made at 65 per cent relative humidity and 70 F., samples should be preconditioned in an atmosphere in the range of 10 to 40 per cent relative humidity at a temperature below 90 F.

Rayon.—Add the following as a new Note 1, renumbering the present note as Note 2:

NOTE 1.—Regenerated cellulose fibers made by the complete saponification of cellulose esters are rayons.

Rayon Modified.—Add the following to this definition: "For example, a fiber spun from viscose containing casein or other protein."

Yarn Number.—Change to read as follows, retaining the present Notes 1, 2, and 3:

Yarn Number, n.—A measure of linear density. Two systems are in current use:

1. Direct Yarn Numbers (Equal to specific linear density):

$$\text{Yarn number} = \frac{\text{Observed linear density}}{\text{Linear density of a No. 1 yarn}}$$

Direct yarn numbers are based on *weight per unit length*. Direct yarn numbers have been recommended in a universal system[a] and are commonly used for most yarn intermediates, and in the silk, jute and man-made fiber industries.

2. Indirect Yarn Numbers (Equal to the reciprocal of the specific linear density):

$$\text{Yarn number} = \frac{\text{Linear density of a No. 1 yarn}}{\text{Linear density, observed}}$$

Indirect yarn numbers (reciprocal numbers) are based on *length per unit weight* and are commonly used in the asbestos, cotton, glass, linen, woolen, and worsted industries.

Tentative Specifications and Methods of Test for Asbestos Yarns (D 299 - 48 T):

The following revisions prepared by Subcommittee A-4 are recommended by Committee D-13:

Section 9(c).—Delete this paragraph.

Section 12(b).—Change the last sentence to read as follows: "The twist of yarn in a shipment shall be the average of three tests from each of the five tubes or bobbins selected in accordance with Section 9(*a*)."

Section 12(c).—Change to read as follows: "The turns per inch of twist in plied yarn shall be determined as described in Paragraph (*b*) with the following exception: The clamps shall be set 10 in. apart."

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[a] Recommended Practice for a Universal System of Yarn Numbering (A.S.T.M. Designation: D 861), 1947 Supplement to Book of A.S.T.M. Standards, Part III-A.

Section 9 (b).—Change the second sentence to read as follows: "Acceptance for breaking strength and yardage tests shall be on the basis of these two additional sets of five sample tubes being within the required limits."

TENTATIVE REVISIONS OF STANDARDS

Standard Methods of Testing Felt (D 461 – 47):

On the recommendation of Subcommittee A-10 the following proposed changes are submitted as a tentative revision of this standard:

Section 2.—Include the following definition of "resilience" along with the present definition of "density." These definitions are to be published as tentative until some satisfactory means of measuring these properties is available.

> *Resilience.*—The property of a material by virtue of which the material is able to do work against restraining forces during return from a deformed state.

Section 7 (a).—Delete the words "of pieces or sheets."

Sections 7 (e) and (f).—Combine these two paragraphs to give the procedure for Cut Parts designating it as Item (*2*), and add the following as a new Paragraph (*e*) and Item (*1*):

> (*e*) *Procedure.*—The thickness shall be measured by one of the following methods depending upon the form of the material:
>
> (*1*) *Pieces or Sheets.*—Three representative specimens, each containing not less than 40 sq. in., shall be cut from the felt in accordance with Section 3. The thickness shall be measured in five locations evenly distributed over each specimen. The average of five readings shall be considered as the thickness of that specimen. The report shall include the maximum, minimum, and average thickness of the three specimens.

New Section.—Add a new Section S7 on pH Determination to read as follows:

> S7. *Determination of pH of Felt:* (*a*) *Sampling.*—A representative sample of the felt weighing approximately 10 g. shall be cut into ⅛ to ¼-in. squares.
>
> (*b*) *Extraction.*—Place the sample in a 500-ml. flask and add 200 ml. of freshly boiled distilled water, and boil for 30 min. under a reflux condenser. Remove and stopper the flask and allow the extract to cool to room temperature.
>
> (*c*) *Determination of pH.*—The pH value shall be determined electrometrically with the glass electrode in accordance with the procedure prescribed in the Tentative Method for Determination of the pH of Aqueous Solutions with the Glass Electrode (A.S.T.M. Designation: E 70).

Standard Specifications for Mechanical Roll Felt (D 944 – 49):

Committee D-13 also recommends the following tentative revision of this standard as submitted by Subcommittee A-10. This revision is submitted as tentative because the method of measuring thickness referred to in Standard Methods D 461 is also in the form of a tentative revision.

Section 7.—Change to read as follows:

> 7. The average of the five thickness readings taken on each specimen in accordance with Section 7 of the Standard Methods of Testing Felt (A.S.T.M. Designation: D 461) shall conform to the thickness requirements prescribed in Table II.

REVISIONS OF STANDARDS, IMMEDIATE ADOPTION

Committee D-13 recommends that the following standards be revised as indicated and accordingly requests the necessary nine-tenths affirmative vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society.

Standard General Methods of Testing Woven Textile Fabrics (D 39 – 39):

The following revisions, prepared by Subcommittee B-1, are recommended by Committee D-13:

Section 9.—Add the following as a new Paragraph (*a*) and designate the present *Section 9* as Paragraph (*b*):

(*a*) Procedures for breaking of fabric by the grab, raveled-strip, and cut-strip, methods as prescribed in Sections 10, 11, and 12 are applicable for dry or wet breaking strength determinations.

New Section.—Add the following as a new Section 13, renumbering the subsequent sections accordingly:

13. *Wet Breaking Strength:* (*a*) *Preparation of Test Specimens.*—When the wet breaking strength of a fabric is required in addition to dry breaking strength, test specimens shall be prepared in accordance with the directions for the grab and strip methods (Sections 10, 11, and 12) with the exception that the test specimens be cut not less than 12 in. in length (Note). Each specimen shall be numbered and then divided into two parts, one 6 in. in length for determining the *dry* breaking strength, and the other for determining the *wet* breaking strength, and each portion shall bear the specimen number. In this manner each break will be performed on test specimens containing the same yarns.

NOTE.—For fabrics which shrink excessively when wet, it will be necessary to cut the test specimens longer in dimension for obtaining wet strength. In such cases, the 6-in. length will be cut for the dry breaking strength, and the remaining longer dimension will be used for determining the wet breaking strength.

(*b*) *Procedure.*—The test specimens for wet breaking strength shall be immersed in tap water to which has been added not more than 0.05 per cent of a nonelectrolytic (neutral) wetting agent at room temperature until thoroughly wetted. The specimens shall then be removed one at a time and tested immediately for wet breaking strength in accordance with the methods specified in Sections 10, 11, and 12 for determining breaking strength. The test of any specimen shall be completed within 2 min. after its removal from the water.

NOTE 1.—This method should be used with caution when testing fabrics which do not wet out uniformly and thoroughly because of the presence of sizing, oil, protective coatings, or water repellents.

NOTE 2.—Where the wet strength of fabric is required in the absence of sizing, water repellents, etc., it will be necessary to subject the cloth to suitable desizing treatments which will not affect the normal physical properties of the fabric, before preparing the test specimens.

NOTE 3.—If, for any reason, it is desired to make allowances for shrinkage in obtaining wet breaking strength by the grab method, the corrected wet breaking strength of the cloth shall be calculated as follows:

$$\begin{aligned}&\text{Corrected wet breaking strength}\\&\quad\text{(grab method only)}\\&\qquad= \frac{\text{Actual wet break} \times \text{dry thread count}}{\text{Wet thread count}}\end{aligned}$$

Standard Specifications for Textile Testing Machines (D 76 – 47):

The revision, appended hereto,[2] of these specifications prepared by Subcommittee B-1 comprises the addition of detailed instructions for verification of constant-rate-of-load machines.

Standards Methods of Testing Felt (D 461 – 47):

Committee D-13 recommends adoption as standard of the following revisions prepared by Subcommittee A-10:

Sections 9 (*b*) *and 10* (*b*).—Change the size of the test specimens in each paragraph from "2 by 10 in." to "2 by 6 in."

New Section.—Add the following as a new Section 10 on Tensile Strength, renumbering the subsequent sections accordingly:

10. *Tensile Strength.*—Tensile strength shall be determined in accordance with the method prescribed in Section 9 except that the thickness of each test specimen shall be measured and the average tensile strength reported in pounds per square inch calculated as follows:

$$\text{Tensile strength, psi.} = \frac{B}{2T}$$

where:

B = average breaking strength in pounds per 2 in. width of test specimen, and

T = average thickness of test specimen in inches.

Committee D-13 recommends for immediate adoption revisions in the following three methods prepared by Subcommittee A-8:

Standards Methods of Testing and Tolerances for Woven Glass Fabrics (D 579 - 47):

Section 8.—Change to read as follows: "8. *Organic Content.*—The organic content shall be not more than that specified."

Section 12.—Change to read as follows:

12. *Organic Content.*—Five test specimens, each weighing not less than 1 g., shall be dried for 1 hr. at 105 to 110 C. (221 to 230 F.) and the weights of the dried individual specimens recorded, weight *A*. The specimens shall then be placed in a ventilated oven and heated for not less than 10 min. at a temperature of 625 ± 25 C. (1157 ± 45 F.). After removal from the oven, they shall be cooled in a desiccator to room temperature and then weighed, weight *B*. The weight of the material removed, weight *A* minus weight *B*, shall be multiplied by 100 and divided by the oven-dry weight of the specimen, weight *A*, to obtain the percentage of organic content. The average of the five determinations shall be the organic content.

Standard Methods of Testing and Tolerances for Woven Glass Tubular Sleeving and Braids (D 581 - 44):

Sections 8 and 12.—Revise to read as indicated above for Sections 8 and 12 in Methods D 579.

Standard Methods of Testing and Tolerances for Woven Glass Tapes (D 580 - 47):

Sections 8 and 16.—Revise to read as indicated above for Sections 8 and 12 of Methods D 579.

Section 17.—Delete this section on Sizing Content as it is unnecessary in view of the changes recommended above.

Subcommittee A-4 prepared the revisions of the following two standards which are recommended by Committee D-13 for immediate adoption:

Standard Specifications and Methods of Test for Asbestos Tape for Electrical Purposes (D 315 - 44):

Section 14 (a).—Delete the word "continuous" in the first sentence.

Section 14 (b).—Add the following to this paragraph: "and at least 75 per cent of the rolls in any shipment shall be in continuous lengths. No roll shall consist of more than two pieces. A roll consisting of two pieces shall be properly marked to indicate the location of the break."

Section 14 (c).—Change to read as follows: "The end of the tape shall be firmly secured. Metallic fasteners are not acceptable."

Standard Specifications and Methods of Test for Asbestos Roving for Electrical Purposes (D 375 - 44):

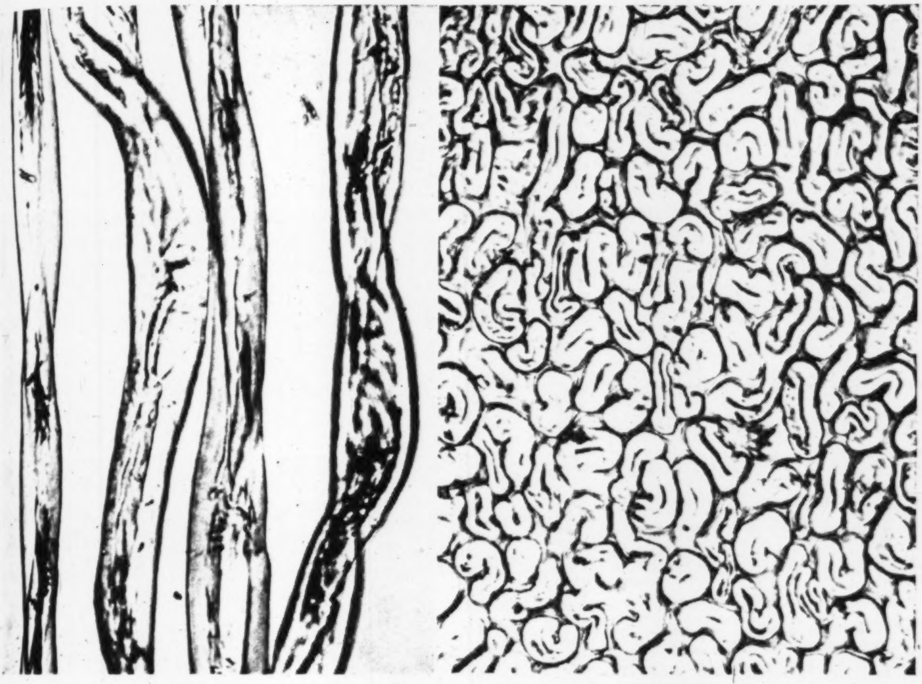
Section 3 (a).—Change the table in this paragraph to read the same as Table I in Section 4 (*a*) of Tentative Specifications D 299.

Section 5.—Change the magnetic rating max., per cent for ferrous roving in the table in this section from "2" to "3."

Section 8 (b).—In the second sentence, change "0.1 g." to read "0.1 grain." In the formula, substitute "7000" for "453.6." In the legend for W in this formula, change "grams" to read "grains."

Section 12.—Change to read as follows:

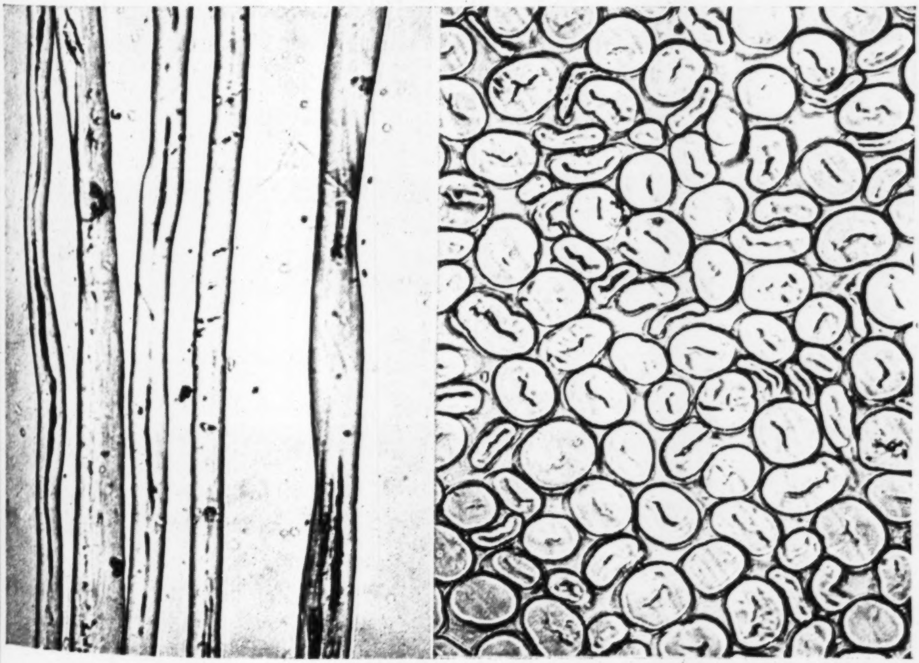
12. *Total Iron.*—Dry a sample of approximately 1 g. to constant weight in an oven at 105 to 110 C., transfer the specimen to a desiccator, allow to cool to room temperature, and then reweigh. This is the oven-dry weight of the specimen, weight *W*. Heat the specimen gently with a bunsen burner to smoke off organic matter and then ignite in a muffle at 650 C. for 20 to 30 min. Transfer the specimen to a 200-ml. porcelain casserole and digest with 50 ml. of HCl (1:1). Without filtering, reduce the ferric iron in this hot solution by adding the stannous chloride solution drop by drop from a buret until the yellow color of the $FeCl_3$ just disappears. The white surface of the porcelain casserole affords a convenient background for determining when sufficient stannous chloride has been added. Cool the solution to 15 C. and while stirring, add 10 ml. of $HgCl_2$ solution. The formation of a light silky precipitate



Courtesy Institute of Textile Technology.

(*a*) Longitudinal View (×500). (*b*) Cross-Section (×500).

FIG. 1.—Cotton Fibers



Courtesy Institute of Textile Technology

(*a*) Longitudinal View (×500). (*b*) Cross-Section (×500).

FIG. 2.—Mercerized Cotton Fibers.

indicates that the conditions are correct. If a dark precipitate of metallic mercury is formed, it indicates that an excess of stannous chloride has been added and the determination shall be repeated using the correct amount of the reducing reagent. Stir the solution vigorously for 1 min., add 3 drops of indicator solution, and dilute to 150 ml., with cold distilled water. Titrate with standard 0.1 *N* $K_2Cr_2O_7$ having a titer no greater than 0.004 g. of Fe_2O_3. The end point is reached when a drop of the potassium dichromate solution produces an intense deep-blue coloration that remains unchanged on the further addition of dichromate.

Section 13.—Change "original" to "oven-dried" specimen.

Sections 14, 15, and 16.—Delete these three sections and renumber Section 17 as 14. Change the center heading from "Magnetic Iron Content" to "Magnetic Iron Rating;" also substitute reference to a new A.S.T.M. method.[3]

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following three tentative specifications and methods be approved for reference to letter ballot of the Society for adoption as standard with revision only in one as indicated:

Tentative Method of Test for Compatibility of Glass Yarn with Insulating Varnish (D 886 - 46 T),

Tentative Specifications for Mechanical Roll Felt (D 944 - 48 T), and

Tentative Methods for Identification of Fibers in Textiles (D 276 - 43 T), revised as follows:

Figures 1 and 2.—Substitute the accompanying Fig. 1 on Cotton Fibers and Fig. 2 on Mercerized Cotton Fibers for the present Figs. 1 and 2.

Tentative Definitions of Terms Relating to Textile Materials (D 123 - 48 T):

The committee recommends that the definitions of the following terms be approved for reference to letter ballot of the Society for adoption as standard and incorporation in Standard Definitions D 123:

Fabric, combustible
Fabric, difficultly combustible or slow burning
Fabric, flammable
Fabric, fire retardant, with name changed to "Fabric, fire resistant."
Fabric, highly combustible (flammable)
Fabric incombustible or noncombustible
Sewing thread
Wool
Yarn, carded
Yarn, combed

ADOPTION OF TENTATIVE REVISIONS AS STANDARD

Standard Methods of Testing Felt (D 461 - 47):

The committee recommends that the present tentative revision of Section 7 (*d*) and the new Section 10 on Bursting Strength be adopted as standard and incorporated in these methods.

Standard Method of Test for Fiber Length of Wool (D 519 - 40):

The committee recommends that the new Section 9 on Cumulative Frequency Curve and the new Fig. 2 showing the Cumulative Length Frequency Curve be adopted as standard and incorporated in this method.

Standard Methods of Testing and Tolerances for Single Jute Yarn (D 541 - 41):

The committee recommends that the tentative revisions of Sections 11 and 16 be adopted as standard and incorporated in these methods.

WITHDRAWAL OF STANDARD AND TENTATIVES

Standard Method of Test for Strength of Rayon and Estron Woven Fabrics When Wet (D 415 - 38),

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[3] This method is published as a suggested method in Appendix VIII of A.S.T.M. Standards on Textile Materials, October, 1949. (Issued as a separate publication.)

Tentative Specifications for All Wool, All Cotton, and Wool and Cotton Blanketing (Household) (D 576 - 40 T),

Tentative Specifications for Medium-Weight Cotton Corduroy Fabrics (D 625 - 41 T), and

Tentative Specifications for Finished, All-Cotton, Upholstery Tapestries (D 678 - 42 T).

Committee D-13 recommends that the standard and tentatives listed above be withdrawn. The withdrawal of Standard Method D 415 is being recommended since a method for determining the strength of fabrics when wet is being recommended for incorporation in Standard Methods D 39.

REAFFIRMATION OF STANDARDS

Standard Specifications and Methods of Test for Tire Fabrics Other than Cord Fabrics (D 122 - 37),

Standard Specifications and Methods of Test for Certain Heavy Cotton Fabrics for Manufacture of Hose and Belting (D 181 - 42),

Standard Methods of Testing and Tolerances for Certain Light and Medium Weight Cotton Fabrics (D 274 - 36),

Standard Method of Determining Relative Humidity (D 337 - 34),

Standard Methods of Testing and Tolerances for Tubular Sleeving and Braids (D 354 - 41),

Standard Specifications and Methods of Test for Holland Cloth (D 376 - 35),

Standard Methods of Testing Pile Floor Covering (D 418 - 42),

Standard Method of Test for Resistance to Yarn Slippage in Silk, Rayon, and Estron Woven Fabrics (D 434 - 42),

Standard Method of Test for Shrinkage in Laundering of Woven Cotton Cloth (D 437 - 36),

Standard Methods of Testing and Tolerances for Yarns Spun from Mixed Fibers (D 508 - 43), and

Standard Methods of Testing Woven Asbestos Cloth (D 577 - 42).

Committee D-13 recommends that the standards listed above which have been published for six years or longer without revision be reaffirmed as there are no immediate changes contemplated in these standards.

REPORT OF COMMITTEE D-14
ON
ADHESIVES*

Committee D-14 on Adhesives held two meetings during the year. A three-day meeting was held in Washington, D. C. on November 10, 11, and 12, 1948. At this session a talk was given by Saul Moses of Johns Hopkins University on a theoretical approach to adhesion. A two-day meeting was held at Chicago, Ill., on April 7 and 8, 1949 at which a talk was given by John H. Wills of the Philadelphia Quartz Co. on properties of sodium silicate as an industrial adhesive.

At the present time, Committee D-14 consists of 86 members, of whom 43 are classified as producers, 30 as consumers, and 13 as general interest members.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1948 Annual Meeting, Committee D-14 presented to the Society through the Administrative Committee on Standards the proposed Tentative Method for Testing the Strength Properties of Adhesives in Shear by Tension Loading (Metal-to-Metal) (D 1002 – 49 T). This recommendation was accepted by the Standards Committee on May 2, 1949, and the new tentative will appear in the 1949 Book of A.S.T.M. Standards.

NEW TENTATIVE

Tentative Method of Test for Cleavage Strength of Metal-to-Metal Adhesives:[1]

This proposed tentative was presented to the Administrative Committee on Standards on July 2, 1948. It was referred back to Committee D-14 with the suggestion that a statement be inserted covering the repeatibility and reproducibility limits of the test. Committee D-14 reviewed the method quite carefully at both the November and April meetings in the light of the suggestion, but believe that the proposed method should be accepted for publication as tentative in its present form and the committee so recommends.

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following four tentatives be approved for reference to letter ballot of the Society for adoption of standards without revision:

Tentative Methods of Test for:

Tensile Properties of Adhesives (D 897 – 46 T),[2]

Peel or Stripping Strength of Adhesives (D 903 – 46 T),[2]

Strength Properties of Adhesives in Shear by Compression Loading (D 905 – 47 T),[3] and

Strength Properties of Adhesives in Plywood Type Construction in Shear by Tension Loading (D 906 – 47 T).[3]

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] This method was accepted as tentative by the Society and appears in the 1949 Book of A.S.T.M. Standards, Part 4.

[2] 1946 Book of A.S.T.M. Standards, Part III-B.

[3] 1947 Supplement to Book of A.S.T.M. Standards, Part III-B.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following five tentatives be continued in their present status without revision pending further evaluation work and revision:

Tentative Methods of Test for:

Resistance of Adhesive Bonds to Chemical Reagents (D 896 – 46 T),[2]
Applied Weight Per Unit Area of Dried Adhesive Solids (D 898 – 47 T),[3]
Applied Weight Per Unit Area of Liquid Adhesive (D 899 – 47 T),[3]
Determining the Effect of Artificial (Carbon-Arc Type) and Natural Light on the Permanence of Adhesives (D 904 – 46 T),[2] and
Impact Strength of Adhesives (D 950 – 47 T).[3]

Committee D-14 has adopted by letter ballot the standard laboratory atmospheric conditions set forth in the Tentative Definitions with Procedures Relating to Conditioning and Weathering (A.S.T.M. Designation: E 41)[4] for all methods where applicable that are under its jurisdiction.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[5]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Strength Properties (M. H. Bigelow, chairman) continues very active. The Section on Tensile Strength is working on a simplified method of tension testing. The present Tentative Method of Test for Tensile Properties of Adhesives (D 897 – 46 T) is being used successfully in a number of laboratories. Three test procedures developed by the Section on Shear Strength have already been published as tentative, two for wood and one for metal, and the section is now evaluating a proposed method for use with plastic materials. The Section on Impact Strength is revising the Tentative Method of Test for Impact Strength of Adhesives (D 950 – 47 T) to modify the jig for holding specimens. Round-robin tests are continuing on flexural test specimens. A suggested method for fatigue testing is being prepared. A Tentative Method of Test for Cleavage Strength of Metal-to-Metal Adhesives has been prepared, as appended hereto.[1] Round-robin work continues on peel testing. A new section on Creep and Flow has been formed to prepare methods of testing for these properties.

Subcommittee II on Analytical Tests (L. Repsher, chairman) has been reactivated to work on methods of determining solids content of adhesives.

Subcommittee III on Permanence (R. F. Blomquist, chairman) is making progress toward its goal of establishing methods of testing permanence of adhesives for specification purposes. The Section on Effect of Moisture and Temperature is conducting round-robin tests on cyclic exposure procedures, and a method for determining the effect of continuous exposure is out to letter ballot of the subcommittee. The Section on Effect of Chemical Reagents is revising the Tentative Method of Test for Resistance of Adhesive Bonds to Chemical Reagents (D 896 – 46 T) to include a screening test and has submitted the revision to letter ballot of Committee D-14, with returns on the letter ballot incomplete at this time. The Section on Effect of Light is continuing round-robin work on the Tentative Recommended Practice for Determining the Effect of Artificial (Carbon-Arc Type) and Natural Light on the Permanence of Adhesives (D 904 – 46 T). The Section on Effect of Biological Factors has run extensive tests on several proposed methods and is now trying to choose the most effective and practical test procedure.

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[4] 1948 Supplement to Book of A.S.T.M. Standards, Part III-B.

[5] The letter ballot vote on these recommendations was avorable; the results of the vote are on record at A.S.T.M. Headquarters.

Subcommittee IV on Working Properties (D. L. Swayze, chairman).—The Section on Consistency has submitted a cup method, an adaptation of the Standard Methods of Testing Nitrocellulose Clear Lacquers and Lacquer Enamels (D 333 – 40), to letter ballot, and several additional methods of determining consistency are receiving consideration in this section. The Section on Coating and Spreading Rate is requesting members of Committee D-14 to use Tentative Methods D 898 and D 899 and report the suitability of the methods. The Section on Slippage and Flow and the Section on Penetration are to be reactivated. The Section on Gap Filling Properties is preparing a method for submission to the subcommittee. The Section on Rate of Strength Development is now ready to submit a proposed method to letter ballot of Committee D-14. A great deal of work has been done by the Section on Tack and Blocking; a tentative method on blocking is ready to be submitted to Subcommittee IV; the work on Tack is in the stage of final evaluation, and on completion a proposed method of test will be written. The Section on Storage Life is rewriting a proposed method for submission to subcommittee ballot.

Subcommittee V on Specifications (G. Reinsmith, chairman).—The work of this subcommittee has been retarded to some extent by a lack of approved methods of test. However, the subcommittee has assumed the task of writing specifications on a general purpose adhesive and an acoustical tile adhesive.

Subcommittee VI on Nomenclature (F. Moser, chairman) has submitted a second set of definitions to the Administrative Committee on Standards,[6] and is continuing work on the definitions of other terms.

Subcommittee VII on Research (R. C. Platow, chairman) has been investigating the problem of pure shear testing and has been studying methods for determining the corrosion resistance of adhesives. At the April meeting, N. J. DeLollis described work under way at the National Bureau of Standards on an investigation of the fundamentals of adhesion.

Subcommittee VIII on Electrical Properties is temporarily without a chairman due to the resignation of G. A. Olsen. Proposed methods for determining arc resistance, power factor, insulation resistance, and dielectric constant are being written at the present time.

This report has been submitted to letter ballot of the committee, which consists of 86 members; 60 members returned their ballots, of whom 56 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

F. W. REINHART,
Chairman.

G. W. Koehn,
Secretary.

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[6] See Editorial Note below.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-14 presented to the Society through the Administrative Committee on Standards the recommendation that the Tentative Definitions of Terms Relating to Adhesives (D 907 – 47 T) be revised. This recommendation was accepted by the Standards Committee on September 22, 1949, and the revised tentative definitions appear in the 1949 Book of A.S.T.M. Standards, Part 4.

REPORT OF COMMITTEE D-15
ON
ENGINE ANTIFREEZES*

Committee D-15 on Engine Antifreezes has held two meetings during the year, both in Washington, D. C.; the first on October 29, 1948, and the second on February 22, 1949. The Advisory Committee and subcommittee meetings were held concurrently. Active study groups of subcommittees have, in many instances, held separate meetings.

The Ordnance Department, through the A.S.T.M. Ordnance Advisory Committee, expressed an urgent need for test methods to be used in the preparation of a performance type specification for glycol antifreeze. This request was accepted by Committee D-15 as a problem for immediate study.

In order to assist the subcommittees in the selection of pertinent test methods, Subcommittee VII on Specifications has been activated. In addition, a special study group has been appointed to formulate standard conditions for sampling and testing antifreeze materials in order that test data on the properties of antifreezes may be more readily correlated.

There have been four resignations and four additions to the list of committee members during the year. At present, there are 40 members serving on the committee of whom 20 are classified as producers, 10 as consumers, and 10 as general interest members.

The following changes in subcommittee chairmanships occurred during the year: R. E. Mallonee, vice D. B. Brooks as chairman of Subcommittee I on Freezing Point Determination; and R. J. Harker, vice R. A. Willihnganz as chairman of Subcommittee IV on Chemical Properties. J. M. Clark was elected chairman of the newly formed Subcommittee on Specifications.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Freezing Point Determination (R. E. Mallonee, chairman) has conducted extensive collaborative tests on three proposed test methods for the determination of the freezing point of antifreeze solutions. It is the feeling of the subcommittee that suggested modifications to the procedure warrant further careful evaluation before the method is submitted to the Society as tentative. The group believes, however, that the information it has accumulated to date is of sufficient value to warrant its publication as information only. The data are accordingly being assembled for submission to the Society.

Subcommittee II on Antifreeze Field Testers (J. D. Klinger, chairman).—As the result of concerted effort on the part of its members, this subcommittee has completed the preparation of a proposed specification for a hydrometer-thermometer antifreeze field tester. This will be submitted to the main committee for approval with the recommendation that it be published as information. Since it is necessary to know accurately the freezing point of antifreeze solutions, for this specification, publication will be delayed until the tentative method of determining freezing point has been completed by Subcommittee I.

With the approval of the Advisory Committee, this subcommittee has changed its name from "Hydrometers for Field Testing" to its present title because the latter is believed to be a more general one and more descriptive of the functions of the group.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27 – July 1, 1949.

Subcommittee III on Physical Properties (H. S. Nutting, chairman) has appointed subgroups to study methods for determining boiling point and specific gravity of antifreezes. Both groups have undertaken cooperative test programs and have prepared test methods for approval by this subcommittee. Further work is in progress to determine the boiling point of mixed antifreezes and the specific gravity of aqueous antifreeze solutions. The proposed methods will be modified, if necessary, to include these broader scopes.

Subcommittee IV on Chemical Properties (R. J. Harker, chairman) is conducting a series of cooperative tests on the following chemical properties of antifreezes and their aqueous solutions: pH and reserve alkalinity, water content, and ash and solids on evaporation.

Work on the classification of antifreezes, assigned to the subcommittee for study has been postponed pending the development of necessary test methods currently under investigation by other subcommittees.

Subcommittee VI on Simulated and Actual Service Testing (E. H. Keller, chairman) has been assigned the specific task of preparing a circulating corrosion test method based on the procedure used by the National Bureau of Standards. This method was selected by the main committee as the one best suited to rapid development for Ordnance Department use in the time allotted. When completed and approved by the committee, it will be submitted to the Society for publication as information.

Although it is not proposed at present to offer this method as tentative, the Study Group on Corrosion and Foaming has started a limited amount of cooperative test work to establish optimum operating conditions. This study group is currently investigating other procedures for corrosion and foaming which have been proposed for consideration as tentative methods by fifteen cooperating laboratories and includes a test method based upon the procedure outlined in Navy Department Specification 51-C-39.

The Study Group on Recommended Cooling System Practices is preparing a short article for publication.

Subcommittee VII on Specifications (J. M. Clark, chairman) was activated to consider important properties for which test methods should be developed by the other subcommittees. This subcommittee has recommended that immediate consideration be given to the following properties:

Freezing point,
Boiling point,
Field testing,
pH and reserve alkalinity,
Corrosion,
Foaming,
Storage stability, and
Solids on evaporation.

Other properties were considered, but recommendations to the committee were temporarily withheld for the following reasons. It was felt that difficulty would be encountered in preparing suitable test methods for heat transfer, seepage, and flammability in the foreseeable future. Viscosity and effect on car finish were believed to be irrelevant to the problem under consideration. It was agreed that toxicity was beyond the scope of A.S.T.M. and was more properly the concern of qualified health organizations.

This report has been submitted to letter ballot of the committee, which consists of 36 voting members; 29 members returned their ballots, of whom 28 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

H. R. Wolf,
Chairman.

E. H. Keller,
Secretary.

REPORT OF COMMITTEE D-17

ON

NAVAL STORES*

Committee D-17 on Naval Stores held one meeting on June 24, 1948, in connection with the Annual Meeting of the Society at Detroit, Mich. A joint informal meeting of all subcommittees was held the previous day for the purpose of considering the reports from the subcommittee chairmen on the previous year's work, deciding what actions should be recommended regarding methods under study, and planning for further work to be done.

Two changes in the committee By-laws were approved for submission to letter ballot. One change would increase the number of members-at-large on the Advisory Committee from four to six; the other would eliminate a requirement that at least two members of such a committee be selected from those serving as subcommittee chairmen.

Additions and changes in the general committee membership bring the voting membership to 41, of whom 15 are classified as producers, 14 as consumers, and 12 as general interest members.

NEW TENTATIVES

Subcommittee IV on Chemical Analysis of Rosin has prepared three test methods for rosin that are considered ready for publication. The committee therefore recommends for acceptance as tentative the following three methods:

Tentative Methods of Test for:[1]

Ash in Rosin,
Iron in Rosin, and
Unsaponifiable Matter in Rosin. This method represents a revision of the Proposed Method of Test for Unsaponifiable Matter in Rosin, which was published as information with the 1944 report of the committee.

REVISION OF TENTATIVE

Tentative Methods of Testing Tall Oil (**D 803 - 44 T**).[2]—Based on comparative tests by several members of Subcommittee V on Tall Oil, it is recommended that this method be revised as follows, and retained as tentative:

Section 30.—Delete the word "modified" in line 2 and change the numeral "1" at the end of the formula to a "2"; also delete the words "corrected (Note)" in the legend of R_1, and the note at the end of this section.

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following two tentatives be approved for reference to letter ballot of the Society for adoption as standard, with revisions as indicated:

Tentative Methods of:

Sampling and Testing Pine Oil (D 802 - 46 T),[2] revised as follows:

Section 7(b).—Delete the last sentence and substitute the following: "Observe and record the temperature when 5 ml. has been collected in the receiving cylinder, and thereafter when the level of the distillate reaches each 10-ml. division on the graduate, including a 95-ml. reading. Discontinue the distillation when the temperature reaches that specified for the minimum percentage requirement after correcting for barometric pressure. Allow the condenser to drain and record the percentage distilled. Should the thermometer reading start to fall before the temperature specified for the minimum percentage requirement is reached, discontinue the distillation, record the maximum temperature reached, allow the condenser to drain, and record the percentage distilled."

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* Presented at the Fifty-second Annual Meeting of the Society, June 27 - July 1, 1949.

[1] These methods were accepted as tentative by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 4.

[2] 1946 Book of A.S.T.M. Standards, Part II.

Section 10 (c).—Add "and increase the rate of boiling" to the end of the ninth sentence. Delete the last four sentences and substitute the following: "At 15 to 20-min. intervals during the test, raise the mercury reservoir slowly to return the supernatant dipentene to the flask, retaining the water in the trap, and again lower the mercury level to collect additional distillate. Discontinue the distillation at the end of 4 hr., and bring down any droplets of water in the condenser with the brush."

Testing Pine Tar and Tar Oil (D 856 - 46 T),[2] revised as follows:

Section 17.—In the third sentence change "distill" to "reflux." Change the fourth sentence to read as follows by the addition of the italicized words and the omission of those in brackets: "When most of the water has *been trapped*, [distilled] increase the rate of *reflux* [distillation] to 200 drops per min. and maintain this [distillation] rate until no more water is collected. In the fifth sentence, change "distillation" to "refluxing."

Section 20.—In the second sentence, delete the words "a small quantity," and substitute therefor "about 15 to 20 mg. of Alkali Blue 6 B (dry powder)." At the end of this section add a note reading as follows: "NOTE.—Alkali Blue 6 B for use as an indicator in this test is the dye identified in the Color Index as No. 703, being the sodium salt of triphenylpararosaniline monosulfonic acid. A dye often sold as Alkali Blue is Alkali Blue 4 B (Color Index No. 704), a mixture of the above with the sodium salt of diphenyl rosaniline monosulfonic acid. Although the latter undergoes the same color change in the transition from acid to alkaline solution, the 6 B indicator is the one recommended for use in this test."

REVISION OF STANDARDS AND REVERSION TO TENTATIVE

The committee recommends that the following standard methods be revised and reverted to tentative:

Standard Method of Test for Acid Number of Rosin (**D 465 - 42**).[2]—The method of determining the titration end point in the test for acid number of dark rosins, as given in the Tentative Method of Test for Acid Number of Dark Rosin (D 465 - 45 T), which was published as a tentative revision of Standard Method D 465, proved to be unsatisfactory for a standardized procedure. Subcommittee IV has developed a more suitable method using an electrometric titration procedure. The committee feels that the present standard and the revised tentative should be combined as appended hereto[3] for publication as a single method of test applicable to all rosins.

Standard Method of Test for Saponification Number of Rosin (**D 464 - 42**).[2]—As in the case of the acid number test, Standard Method D 464 for saponification number of rosin was found unsuitable for testing the darker grades. The electrometric titration method was found satisfactory for all grades of rosin. In order to have available both procedures is a single A.S.T.M. method, the committee recommends that the electrometric method be incorporated with the standard method into the combined method appended hereto[3] and published as tentative until it can again be recommended for adoption as standard.

STANDARD CONTINUED WITHOUT REVISION

The committee has reviewed the Standard Method of Test for Toluene Insoluble Solid Matter in Rosin (Chiefly Sand, Chips, Dirt, and Bark) (D 269 - 30)[2] and recommends that it be continued as standard without revision.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the Tentative Methods of Test for Volatile Oil in Rosin (D 889 - 46 T)[2] and the Test for Water in Liquid Naval Stores (D 890 - 46 T)[2] be continued as tentative as these tentatives are still under collaborative study, and no recommendations can be made at this time.

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[3] These revised methods were accepted by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 4.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

ACTIVITIES OF SUBCOMMITTEES

Since wooden barrels are no longer used as commercial containers for rosin, consideration is being given by the committee to changes in the Standard Methods of Sampling and Grading Rosin (D 509 - 45). This revision will be presented in the 1950 report of the committee.

Subcommitteee I on Softening Point of Rosin (J. M. Schantz, chairman).—Efforts are being made through Committee E-1 on Methods of Testing, and with the cooperation of other interested technical committees, to work out a basis for combining the two Ring-and-Ball Softening Point Methods, E 28 and D 36, into a single A.S.T.M. standard applicable to all resinous and bituminous materials, with flexibility to permit such variations as may be necessary with different types of material. The incorporation of an optional bath heating method using a submerged resistance coil with voltage control is also under consideration.

Subcommittee III on Volatile Oils in Rosin (S. R. Snider, chairman).—Collaborative work is now under way to study the present Tentative Method of Test for Volatile Oil in Rosin (D 889 - 46 T) by running this test on three samples of gum rosin with high volatile oil content that were produced accidentally on commercial turpentine distilling equipment of various types. No final report has been made on this work.

Subcommittee IV on Chemical Analysis of Rosin (W. D. Pohle, chairman) has been very active in studying methods that can be used for determining acid and saponification numbers of both light and dark rosins, also other determinations. The results of this work are embodied in the recommendations affecting Standard Methods D 464 and D 465 and the three new tentatives presented for publication, as appended hereto.[1]

Subcommittee V on Tall Oil (A. Pollak, chairman).—Several members of the committee have been doing some work in an effort to determine the relationship between the results obtained on rosin acid number of tall oil by the alternative modified Wolfe and McNicoll esterification methods. While consideration is being given to withdrawing the McNicoll method from Tentative Methods D 803, no final decision has been reached. A correction in the McNicoll formula for computing rosin acid number is being recommended.[5] Tests are also being made of an electrometric titration method in the Wolfe procedure for rosin acid number.

Subcommittee VI on Pine Tar (J. P. Bain, chairman).—While no collaborative work was done last year on pine tar samples, a careful study of previous collaborative tests seemed to warrant a recommendation for adoption as standard of the Tentative Methods of Sampling and Testing Pine Tars and Pine-Tar Oils (D 856 - 46 T) with some minor revisions.

Subcommittee VII on Terpene Hydrocarbons and Pine Oil (R. E. Price, chairman).—This subcommittee, in addition to making the tests that led to the recommendation for adoption as standard of Tentative Pine Oil Methods D 802, has been working on two methods of test applicable to turpentine, namely, for determining evaporation residue and acidity, calculated as acid number. Evaporation residue is a test applied to turpentine in some European countries, and it was thought advisable to have available a standard A.S.T.M. test procedure, even though it is not customary for American buyers and users of turpentine to make this determination. High acidity in turpentine, especially in gum turpentine, has been found to have a detrimental effect on its keeping quality, and rate of discoloration after being stored in tanks or shipped in steel drums. The acidity consists of a water-soluble portion, and a water-insoluble portion, the latter being the more troublesome, and caused by too rapid distillation of the pine gum. The test procedures, given in Appendix I will be referred to Committee D-1 on Paint, Varnish, Lacquer and Related Products through its Subcommittee V on Volatile Solvents, as soon as they receive final approval of Committee D-17. A change in the specifications covering specific gravity of destructively distilled wood turpentine is also being considered.

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[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

[5] See Editorial Note on p. 466.

Subcommittee VIII on Rosin Oil (V. E. Grotlisch, acting chairman).—At the 1944 meeting, the committee voted to authorize a subcommittee on rosin oil. Due to war conditions and other circumstances, it has been impossible to organize this subcommittee and to find a chairman who could devote the necessary time to the work. In order, however, to bring the subject of rosin oil into more active status, the general committee chairman has collected information on rosin oil test methods and has prepared a set of suggested methods for further study. These methods are published in Appendix II as information to elicit suggestions.

This report has been submitted to letter ballot of the committee, which consists of 41 voting members; 30 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

V. E. GROTLISCH,
Chairman.

W. A. KIRKLIN,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-17 presented to the Society through the Administrative Committee on Standards the recommendation that the Tentative Methods of Testing Tall Oil (D 803 – 44 T) be revised. This recommendation was accepted by the Standards Committee on September 22, 1949, and the revised tentative methods appear in the 1949 Book of A.S.T.M. Standards, Part 4.

APPENDIX I

PROPOSED TESTS FOR EVAPORATION RESIDUE AND ACIDITY OF TURPENTINE[1]

Since turpentine comes within the scope of interest of Committee D-17, although the Standard Methods of Sampling and Testing Turpentine (D 233) are published under the jurisdiction of Committee D-1 on Paint, Varnish, Lacquer and Related Products, Committee D-17 has developed the following proposed tests for evaporation residue and acidity of turpentine. These proposed tests are published as information only. When these tests have been approved by Committee D-17, they will be recommended to Committee D-1 for inclusion in Methods D 233.

EVAPORATION RESIDUE

Procedure

15. (*a*) With a small pipet, deliver approximately 10 g. (12 ml.) of turpentine into a tared, flat-bottom, straight-side aluminum (milk evaporating) dish 75 mm. in diameter and 20 mm. in depth. Weigh to the nearest 0.01 g.

(*b*) Place the dish on a boiling water or steam bath for exactly 60 min. Remove the dish, wipe off the outside, and place in an oven maintained at 105 ± 2 C. for an additional 60 min. Remove, cool in a desiccator, and weigh.

(*c*) Replace the dish in oven for an additional 15 min. and again cool and weigh. If the loss in weight for such an additional heating period does not exceed 0.02 g., record this last weight as the end point of the test. If the loss in weight during such an additional period exceeds 0.02 g., repeat the 15-min. reheating periods until the loss in weight for such a period does not exceed 0.02 g.

Calculation and Report

16. Subtract the tare weight of the dish from the last weight to obtain the weight of residue. Calculate and report the percentage of evaporation residue to the nearest 0.1 per cent.

Precision

17. Duplicate tests should agree within 0.2 per cent.

ACIDITY

Reagents

18. (*a*) *Sodium Chloride Solution.*—Dissolve 100 g. of U.S.P. or c.p. NaCl in 1 liter of distilled water.

(*b*) *Standard Alcoholic Potassium Hydroxide Solution (0.1 N).*—Prepare a solution of 6.6 g. potassium hydroxide in either 82 per cent isopropyl alcohol or 90 per cent methyl alcohol, as follows: Dissolve 6.6 g. of KOH in 100 ml. of CO_2-free water, then dilute to 1 liter with either 91 per cent isopropanol or 99.5 per cent methanol; or dissolve 6.6 g. of KOH in 170 ml. of water and dilute to 1 liter with 99 per cent isopropanol. Standardize against a standard 0.1 *N* acid.

(*c*) *Solvent.*—Neutral isopropyl alcohol, of either the 99 per cent (preferred) or 91 per cent grade. Prepare by adding alcoholic KOH solution dropwise until a pink color is obtained with phenolphthalein.

(*d*) *Phenolphthalein Indicator Solution.*

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[1] Published as information, June, 1949 as suggested additions to the Standard Methods of Sampling and Testing Turpentine (D233-48), 1946 Book of A.S.T.M. Standards, Part II, p. 1559.

Procedure

19. (*a*) Measure 100 ml. of turpentine in a graduated cylinder and transfer to a 500-ml. separatory funnel. Add 100 ml. of NaCl solution, stopper, and shake vigorously for about 20 sec. Allow to settle and draw off all the salt solution into a 250-ml. Erlenmeyer flask. Do not wash the turpentine. Titrate the salt solution with KOH solution, using 0.5 ml. of phenolphthalein indicator.

(*b*) Draw the turpentine into a 300-ml. Erlenmeyer flask and wash the separatory funnel twice with 50-ml. portions of isopropyl alcohol solvent, adding these washings to the turpentine. Shake to effect solution of the turpentine in the solvent, add 0.5 ml. of phenolphthalein indicator, and titrate with KOH solution to a light pink end point that persists for 1 min. or more, keeping the flask stoppered.

Calculation and Report

20. (*a*) Calculate separately the water-soluble acid number and the alcohol-soluble acid number, in milligrams of KOH per gram of sample, as follows:

$$\text{Acid number} = \frac{AN \times 56.1}{86}$$

where:

A = milliliters of KOH solution required for titration (Paragraph (*a*) for water-soluble acid number and Paragraph (*b*) for alcohol-soluble acid number),

N = normality of the KOH solution, and

86 = assumed weight in grams of the 100-ml. sample used.

(*b*) Report the results to the second decimal place.

Precision

20. Duplicate results should agree within 0.02.

APPENDIX II

SUGGESTED METHODS OF TEST FOR ROSIN OILS

PROPOSED BY V. E. GROTLISCH[1]

Scope

1. These methods of test are intended for use in determining whether a rosin oil conforms with any of the specifications and requirements usually applied to ensure its suitability for any given use. In general, not all of the tests will be required to determine the fitness of an oil for a specific use. The term "rosin oil" includes the oils obtained by dry destructive distillation of rosin, with or without subsequent redistillation, and also certain compounded oils prepared from a rosin oil base. It has no relationship to the product formerly known as liquid rosin, for which the term "tall oil" has been adopted.

Appearance

2. Examine a sample of the oil in a clear glass tube by transmitted light, to ascertain whether any separated water, crystals, or insoluble foreign matter are present.

Color

3. (*a*) Determine the color of the oil by reference to the A.S.T.M. Color Numbers, according to the Standard Method of Test for Color of Lubricating Oil and Petrolatum by Means of A.S.T.M. Union Colorimeter (A.S.T.M. Designation: D 155).[2]

(*b*) Compare the color of the oil with any suitable or specified reference standard, using a vessel similar to that in which the reference standard is contained. When non-liquid standards are used, the container shall be specified in terms of the distance between two opposite faces through which the oil is viewed, and such distance shall be shown on the report.

(*c*) For oils of such dark color that accurate and satisfactory color comparisons can not be made, a portion of the oil shall be diluted with an equal quantity of redistilled toluene, and the color shall be determined on such diluted oil. In such case the report shall carry the notation "50 per cent toluene dilution."

Specific Gravity

4. Determine the specific gravity of the oil at 25 C. (77 F.) by means of any convenient apparatus that has been calibrated at 15.56 C. (60 F.). Report the specific gravity to the third decimal as:

Specific gravity, 25/15.56 C. (77/60 F.)

Such observed specific gravity may be converted to the 25/25 C. (77/77 F.) basis by multiplying the observed reading by the factor 1.002.

NOTE.—If a Hubbard pycnometer or weighing bottle is used, the weight of water contained by the pycnometer at 25 C. shall be determined, in which case the ratio of oil to water will be the specific gravity at 25/25 C. To convert this to the 25/15.56 C. (77/60 F.) basis, multiply by the factor 0.998.

Viscosity

5. (*a*) Determine the viscosity of the oil at 25 C. (77 F.) by comparing the rate

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[1] Production and Marketing Administration, Department of Agriculture, Washington, D. C., Chairman of Committee D-17.

[2] 1949 Book of A.S.T.M. Standards, Part 5.

of movement of an air bubble through the oil in a closed tube with the movement of similar size bubbles in any suitable liquid reference standards. The identity of such standards shall be shown in the report.

(*b*) Determine the viscosity of the oil by means of a standard viscosimeter by one of the following procedures:

(*1*) At 130 F. or 210 F., using a Saybolt Universal Viscosimeter, in accordance with the Standard Method of Test for Saybolt Viscosity (A.S.T.M. Designation: D 88).[2] Report the viscosity in seconds.

(*2*) At 30 or 50 C., using a Stormer Viscosimeter, in accordance with Sections 9 to 11 of the Tentative Methods of Sampling and Testing Pine Tars and Pine-Tar Oils (A.S.T.M. Designation: D 856).[3] Report the viscosity in seconds per 100 revolutions, or convert the observed reading to centipoises by means of the formula given in Section 12 of Methods D 856.

Flash Point

6. Determine the flash point of the oil either in accordance with the Standard Method of Test for Flash and Fire Points by Means of Open Cup (A.S.T.M. Designation: D 92),[2] or in accordance with the Standard Method of Test for Flash Point By Means of The Pensky-Martens Closed Tester (A.S.T.M. Designation: D 93).[3] Report the method used.

Acid Number

7. Weigh 4.95 to 5.05 g., to the nearest 0.01 g., of the sample into a 300-ml. Erlenmeyer flask. Add 100 ml. of a solvent containing equal parts of acetone and either 95 per cent ethyl alcohol (Formula No. 3A or No. 30 denatured) or methyl alcohol. Place on a steam bath and dissolve the oil in the solvent, connecting an air-tube condenser to the neck of the flask and heating for not more than 15 min., if necessary. Cool, add 1 ml. of phenolphthalein indicator solution, and titrate with either aqueous or alcoholic 0.2 N standard alkali solution. Calculate the acid number, in milligrams of KOH per gram of sample, as follows:

$$\text{Acid number} = \frac{\text{ml. alkali solution} \times N \times 56.1}{5}$$

where N is the normality of the standard alkali solution.

Free Rosin Acids

8. Calculate the percentage of free rosin acids in the oil, on the basis of a molecular weight of 346 for such acids, as follows:

$$\text{Rosin acids, per cent} = \frac{\text{ml. alkali solution} \times N \times 0.346 \times 100}{5}$$

$$= \text{acid number} \times 0.617$$

NOTE.—If the sample is a compounded oil containing tall oil or other fatty acid components, it will be necessary to determine the rosin acid number by an esterification process such as the modified Wolfe procedure given in the Standard Methods of Testing Tall Oil (A.S.T.M. Designation: D 803),[3] after which the percentage of rosin acids present is determined by multiplying the rosin acid number by the factor 0.617.

Volatile Matter

9. Weigh 5.0 g. of the oil into a tared flat-bottom straight-side metal dish having a diameter of approximately 3 in. Place in an oven at 105 ± 2 C. for 2 hr. Remove to a desiccator, cool, and weigh. The loss in weight shall be reported as volatile loss on heating, to the nearest 0.1 per cent.

Moisture

10. (*a*) Determine the moisture in rosin oil on a 200-ml. sample in accordance with Sections 15 to 17 of A.S.T.M. Methods D 856, or as described in the Standard Method of Test For Water in

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[3] 1949 Book of A.S.T.M. Standards, Part 4.

Petroleum Products and Other Bituminous Materials (A.S.T.M. Designation: D 95),[3] using either xylene or a petroleum naphtha as the solvent.

(*b*) *Alternate Method.*—Determine moisture in the oil in accordance with the Standard Method of Test for Water and Sediment in Petroleum Products by Means of Centrifuge (A.S.T.M. Designation: D 96).[2]

Ash

11. Determine the ash in rosin oil according to the Tentative Method of Test for Ash In Rosin (A.S.T.M. Designation: D 1063).[3]

Mineral Oil

12. Transfer 10 ml. of the rosin oil to a 300-ml. round-bottom Florence flask, and cool by immersion of the body of the flask in an ice bath. Introduce dropwise into the sample from a dropping pipet, 40 ml. of fuming nitric acid, starting at a rate of 1 drop per 2 sec. and shaking the flask after each drop falls into the sample. When the reaction becomes less violent, the interval between drops may be shortened. When all the acid has been added, shake the contents of the flask vigorously for a few seconds, keeping it cool until the reaction is complete.

(*b*) Transfer the sample to a 50-ml. graduated cylinder and allow to stand. Unreacted mineral oil will rise to the surface of the mixture. The refractive index of the mineral oil should be less than 1.500.

(*c*) Read the volume of mineral oil and calculate the percentage to the nearest 0.2 per cent.

REPORT OF COMMITTEE D-18
ON
SOILS FOR ENGINEERING PURPOSES*

Committee D-18 on Soils for Engineering Purposes held one meeting during the past year at the Annual Meeting of the Society in Detroit, Mich., on June 22, 1948. A joint meeting of the Executive Subcommittee and the subcommittee chairmen was held in Washington, D. C., on December 6, 1948.

Five new members were appointed to the committee and nine members were separated from the committee during the year.

Committee D-18 was represented by E. J. Kilcawley and F. J. Converse at the Second International Conference on Soil Mechanics and Foundation Engineering held in Rotterdam, Holland, during June, 1948. A paper on "The Activities of the American Society for Testing Materials in Soil Testing and Research," was prepared for the Conference by Messrs. Kilcawley and Housel.

The chairman of the Administrative Committee on Research brought to the attention of Committee D-18 certain suggestions and proposals relating to the furtherance within the committee of research on materials and testing. The subcommittee chairmen have been advised of this request and are preparing lists of probable research projects in their sphere of activities.

Inasmuch as there is some overlapping of work being handled by the D-4-D-18 Joint Subcommittee and the "R" subcommittees of Committee D-18, H. F. Clemmer and Harold Allen were appointed during the 1948 Annual Meeting to discuss the problems arising with members of the D-4 and D-18 subcommittees involved. Mr. Clemmer reported that after a discussion with the officers of Committee D-4, it was agreed that any research work being done by the "R" subcommittees would not conflict with the activities of Committee D-4 or the joint subcommittee, but that when the results of such work is referred to the "S" subcommittees for use in connection with standards, they should be processed through the joint subcommittee. Committee D-4 further believed that Committee D-18 should handle any research work in stabilized soils that it desires, but that the standards for such work relating to highways should definitely be handled through the joint subcommittee. It was felt by the members of the Executive Subcommittee that the joint subcommittee should be listed under the "S" subcommittees and the designation of "S-2" was given to this subcommittee.

The Special Subcommittee on Procedure in Soil Testing which was appointed to revise the 1944 edition of "Procedures for Testing Soils," has been working throughout the year on this revision. The subcommittee canvassed all available sources to secure numerous suggested tests for this book. Thirty-nine new suggested test procedures or revisions of present test procedures were received. Eight of the old procedures were withdrawn. It is expected that the work of the special subcommittee will be completed by early fall and that the new edition of "Procedures for Testing Soils" will be ready for general distribution by early winter.

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*Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

Committee D-18 plans to hold a regular meeting during the Pacific Area National Meeting in San Francisco, Calif., during October, 1949. Mr. F. J. Converse, who is a member of the West Coast Committee for Securing Papers, is arranging the program with the aid of C. W. Allen, chairman of the Special Papers Committee.

CONTINUATION OF TENTATIVES WITHOUT REVISION

The committee recommends that the following tentatives be continued in their present status without revision:

Method of:

Test for Moisture-Density Relations of Soils (D 698 – 42 T),
Test for Specific Gravity of Soils (D 854 – 45 T),
Testing Soil-Bituminous Mixtures (D 915 – 47 T),
Test for Shear Strength of Flexible Road Surfaces, Subgrades and Fills by the Burggraf Shear Apparatus (D 916 – 47 T),
Mechanical Analysis of Soils (D 422 – 39), and

Definitions of Terms and Symbols Relating to:

Soil Mechanics (D 653 – 42 T).

ACTIVITIES OF SUBCOMMITTEES

Subcommittee G-2 on Special Papers (E. F. Bennett, chairman) made the necessary arrangements to have the following papers presented at the 1949 Annual Meeting of the Society:

"The Procedure and Significance of Chemical and Mineralogical Tests on Soils,"[1] by T. William Lambe and V. F. B. de Mello.

"Subsurface Explorations by Geophysical Methods,"[2] by E. Raymond Shepard.

"Study on Mechanical Oscillators,"[3] by R. K. Bernhard.

This subcommittee is also assisting in securing papers for the Pacific Area National Meeting.

Subcommittee G-3 on Nomenclature and Definitions (E. A. Abdun-Nur, chairman).—Definitions needing revision and new terms and symbols have been listed and distributed to the subcommittee members for development. Research work necessary to develop a complete list is now being carried out by the members who will make recommendations as to their findings. The final list will be coordinated with the similar committee of the American Society of Civil Engineers and then will be circulated for comment.

Subcommittee R-1 on Surface and Subsurface Reconnaissance (L. E. Gregg, chairman).—The activities of this subcommittee have been limited to the clarification of the scope of its work with relation to other subcommittees and sponsorship of papers for the 1949 annual and fall meetings of the Society.

Subcommittee R-2 on Borings and Sampling for Soil Investigation (J. O. Osterberg, chairman) held its first meeting in Detroit on June 21, 1948, during which time the sections were organized. This subcommittee has approved the proposed revision of the Standard Methods of Surveying and Sampling Soils for Highway Subgrades (D 420 – 45).

Section C on Embankment Materials (E. A. Abdun-Nur, chairman) held an organization meeting in Detroit on June 21, 1948, and formulated a working plan. A tentative procedure for the sampling of embankment materials is being formulated.

Subcommittee R-3 on Physical Characteristics of Soil (Harold Allen, chairman): Section A on Grain Size and Specific Gravity, E. E. Bauer, chairman, was given the responsibility for the preparation of a new method of test for the amount of material finer than the No. 200 sieve for soil and the revision of the Standard Method of Mechanical Analysis of Soils (D 422 – 39) and the Tentative Method of Test for Specific Gravity of Soils (D 854 – 45 T).

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[1] See p. 977.
[2] See p. 993.
[3] See p. 1016.

Committee members now have the second draft of the proposed method of testing soil fractions finer than the No. 200 mesh sieve. The section will recommend to Subcommittee R-3 that the present Standard Method D 422 be reverted to tentative and that the tentative revision of this standard submitted in August, 1942, be included. Research studies on air dispersion cups, dispersing agents, and hydrometer design are currently being carried out by the section.

Several changes in the Tentative Method D 854 are being recommended to the committee for approval. Provision is made in the revised version for the method of test for particles larger than the No. 4 sieve and for the use of kerosine when desired instead of water. The provision for pulverizing particles larger than the No. 4 sieve has been eliminated.

Subcommittee R-5 on Structural Properties of Soil (D. M. Burmister, chairman): Section A on Consolidation, D. M. Burmister, chairman, has been carrying out research during the year on:

1. The preparation of undisturbed and compacted samples and the effect of sample disturbance.

2. Methods of loading specimens by progressive *versus* uniform increments. This includes the study of sensitivity of soils to the method of loading.

3. Direct permeability test methods for the determination of time-consolidation relations.

Section B on Direct Shear (F. J. Converse, chairman) prepared a revised edition of the "Method of Test for Shearing Resistance of Soil by a Direct Shear Method" for inclusion in the new edition of the "Procedures for Testing Soils." This section plans to study the shearing resistance of clays by the direct shear method during 1949.

Section C on Methods of Testing Soils under Triaxial Loading (W. G. Holtz, chairman) will sponsor a round table discussion on triaxial testing during the June, 1949, meeting to include triaxial testing equipment, triaxial test procedures, triaxial test data analysis, and a discussion of recent findings.

Subcommittee R-6 on Physico-Chemical Properties of Soils (E. F. Preece, chairman) plans to hold an organization meeting during the Annual Meeting of the Society in June, 1949.

Subcommittee R-8 on Special and Construction Control Tests (H. F. Clemmer, chairman).—Although this subcommittee or its sections have held no meetings during the year, considerable progress has been made toward completing its organization.

Subcommittee R-9 on Dynamic Properties of Soil (R. K. Bernhard, chairman) will hold a joint meeting with Subcommittee R-1 to discuss the overlapping scopes of their activities. A comprehensive list of publications referring to soil dynamics has been started.

Subcommittee R-10 on Bearing Tests of Soil in Place (L. A. Palmer, chairman): Section B on Pile Load Bearing Tests (A. E. Cummings, chairman).—A tentative method covering pile load tests has been prepared and submitted to the subcommittee members for consideration and comment.

Subcommittee S-1 on Specifications and Methods of Tests (F. J. Converse, chairman) recommends that the proposed revision of Standard Method D 420, prepared by Subcommittee R-2 be referred to letter ballot of Committee D-18.

This report has been submitted to letter ballot of the committee, which consists of 98 voting members; 72 members returned their ballots, of whom 71 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

E. J. KILCAWLEY,
Chairman.

R. F. BLANKS,
Secretary.

REPORT OF COMMITTEE D-19
ON
INDUSTRIAL WATER*

Committee D-19 on Industrial Water and all of its subcommittees held meetings at the Annual Meeting of the Society in Detroit, Mich., June 24 and 25, 1948, and at the Spring Group meetings of A.S.T.M. committees in Chicago, Ill., March 3 and 4, 1949.

Organization changes include the following: In Subcommittee III on Methods of Sampling, Section B on Sampling of Water-Formed Deposits becomes a subsection of Section A on Water, and in Subcommittee V on Classification, a new Section on Nomenclature and Terminology has been established. The newly formed Subcommittee VII on Water-Borne Industrial Waste was organized on October 19, 1948, in Pittsburgh, Pa., with four sections:

A on Critical Constituents of Water-Borne Industrial Waste,
B on Methods of Analyses for Water-Borne Industrial Waste,
C on Methods of Sampling, Gaging, and Preservation of Samples, and
D on Methods of Reporting Analytical Results.

The committee sponsored jointly with the Joint Research Committee on Boiler Feedwater Studies a Session on Water which was presented at the Annual Meeting of the Society on June 24, 1948, in the form of a Panel Discussion on "The Influence of Non-ferrous Metals and Their Compounds on the Corrosion of Pressure Vessels."[1]

Committee D-19 is sponsoring a Session on Water at the Annual Meeting of the Society at Atlantic City, N. J., on June 30, 1949, in the form of a round table discussion on "The Need for Standards for the Examination of Water-Borne Industrial Wastes," at which the following papers[2] will be presented:

Introduction by L. Kermit Herndon, Chemical Engineering Dept., Ohio State University, Columbus, Ohio.

"Gaging and Sampling Water-Borne Industrial Wastes," by C. F. Hauck, Hall Laboratories, Inc., Pittsburgh, Pa.

"Analysis of Water-Borne Industrial Wastes: the Need for Uniformity in Methods of Analysis and Reporting," by G. D. Beal and S. A. Braley, Mellon Institute of Industrial Research, Pittsburgh, Pa.

The Subcommittee on the Care of Steam Boilers and Other Pressure Vessels in Service, Chemical Section (formerly called the Feedwater Subcommittee), of the A.S.M.E. Boiler Code Committee. on which the A.S.T.M. is represented, held no meetings during 1948. Comments that have been supplied on the "Proposed Revisions and Addenda to Suggested Rules for the Care of Power Boilers, Section VII of A.S.M.E. Boiler Construction Code,"[3] are being reviewed.

The Executive Committee of the Joint Research Committee on Boiler Feedwater Studies, on which A.S.T.M. is represented, met at the Annual Meeting of the A.S.T.M. on June 24, 1948, and at the Annual Meeting of the A.S.M.E., in New York, N. Y., on Dec. 2, 1948. The major activities of the Joint Research Committee during

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 48, pp. 897–941 (1948).

[2] ASTM BULLETIN, No. 162, December, 1949, p. 35.

[3] *Mechanical Engineering*, pp. 557–560, June, 1948.

1948 included the co-sponsorship of programs of technical papers with various national engineering societies and the organization of three subcommittees on Deposits, Corrosion, and Steam Contamination.

NEW TENTATIVES

The committee recommends for publication as tentative the following four methods as appended hereto:[4]

Tentative Method of Sampling Steam.—This method includes theory of sampling, procedure, and apparatus required to secure samples for determining steam contamination using the calorimeter or chemical and electrical analytical methods.

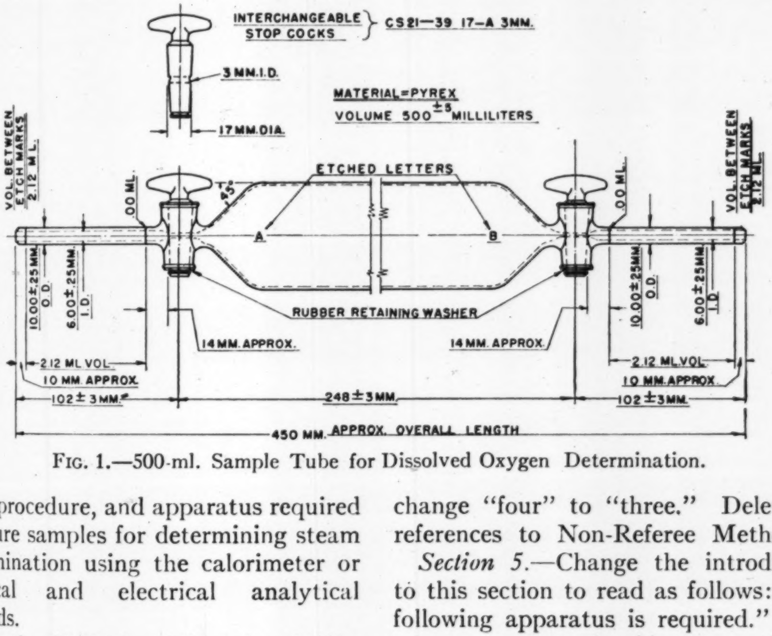
INTERCHANGEABLE STOP COCKS
CS21—39 17—A 3MM.
3 MM. I.D.
17 MM. DIA.
MATERIAL=PYREX
VOLUME 500 ±5 MILLILITERS
VOL. BETWEEN ETCH MARKS 2.12 ML.
.00 ML.
45°
ETCHED LETTERS
A
B
10.00±.25 MM. O.D.
6.00±.25 MM. I.D.
RUBBER RETAINING WASHER
14 MM. APPROX.
14 MM. APPROX.
2.12 ML. VOL.
10 MM. APPROX.
102±3 MM.
248±3 MM.
102±3 MM.
450 MM. APPROX. OVERALL LENGTH

FIG. 1.—500-ml. Sample Tube for Dissolved Oxygen Determination.

Tentative Methods of Test for Acidity and Alkalinity in Industrial Water.—These methods include the application of pH procedures as well as other procedures utilizing indicators to establish end point of titration.

Tentative Methods of Test for Suspended and Dissolved Solids in Industrial Water.—Gravimetric procedures are described for conducting evaporation of relatively pure water in a protected system with automatic control, as well as a procedure for evaporation of industrial water.

Tentative Method of Test for Iron in Industrial Water.—A colorimetric procedure is described for the determination of iron.

REVISION OF TENTATIVE

Tentative Methods of Test for Dissolved Oxygen in Industrial Water (**D 888 - 46 T**).[5]—Committee D-19 recommends the following revisions in this method:

Section 1.—In the second sentence, change "four" to "three." Delete the references to Non-Referee Method C.

Section 5.—Change the introduction to this section to read as follows: "The following apparatus is required." Add a new paragraph (*e*) to read: "(*e*) *Graduated Cylinder.*—A 10-ml. graduated cylinder with 1-ml. divisions." Reletter the subsequent paragraphs accordingly.

Add a new note at the end of this section to read as follows:

NOTE *2.*—The end point may also be detected by means of "dead-stop" titration apparatus.[a]

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[4] These methods were accepted as tentative by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 5.

[5] 1946 Book of A.S.T.M. Standards, Part III-A.

[a] See the paper by R. C. Ulmer, J. M. Raynar, and J. M. Decker, "Applicability of the Schartz-Guerney Method for Determining Dissolved Oxygen in Boiler Feedwater and Modification of the Method to Make It Especially Applicable in the Presence of Such Impurities as Are Encountered in Power Plants," *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 1258 (1943).

Fig. 1.—Replace this figure with the accompanying new Fig. 1.

Section 7(a).—Change the first sentence to read as follows: "Arrange the two sample tubes in a support so that they are vertical, with their upper outlets free of hose connections and at a higher level than the valve for adjustment of sample flow." In the fifth sentence, change "sample flow adjustment" to read "adjusting the flow of sample."

Section 7 (b).—In the second sentence, add a reference to Note 6 after the word "tubes." Delete the third sentence. Add a reference to Note 3 at the end of the sixth sentence. In the eighth sentence, add "2.0-ml." before the word "calibration." In the third sentence from the end of the paragraph change the reference to "Note 3" to "Note 4." Change the next to the last sentence to read as follows: "Add to the *sample* an amount of H_2SO_4 solution to fill the nipple to the upper calibration point, rinse both ends of the flask, and again mix thoroughly."

Add the following new note: "NOTE 3.—An error is introduced in the determination if precisely the same point on the meniscus at upper and lower calibration marks is not used."

Renumber "Note 3" as "Note 4." In the last line of this note, change "$MnSO_4$" to read "H_2SO_4."

Section 7 (c).—At the beginning of this paragraph, add a new sentence to read as follows: "Invert the sample tube and drain out 4 to 10 ml. of the sample (Note 6) into the 10-ml. graduated cylinder. Record the volume withdrawn and discard it."

Add the words "rest of the" before "sample" in the present first sentence. Change the reference to "Note 4" to "Note 5." In the eighth sentence, delete the present reference to Note 5 and add the following at the end of the sentence: "(Note 7), allowing a sufficient interval between additions to enable electrodes and solution to come to equilibrium."

Renumber "Note 4" as "Note 5" and renumber "Note 5" as "Note 7," and add a new Note 6 to read as follows:

NOTE 6.—If the larger tube of a pair of sample tubes is used for the *sample*, the small volume withdrawn and discarded frequently may be selected to equalize the volume of *sample* and *blank*, thereby improving accuracy of calculation by the rapid method.

Section 8.—In the legend under the calculations, change the definition of "V_s" to read as follows: "V_s = volume of *sample* in milliliters (volume of sample tube minus volume of portion discarded immediately before titration (Section 7 (*c*))."

Section 11.—Change the introduction to read as follows: "The following apparatus is required."

Sections 16 to 21.—Delete these sections which cover the present Non-Referee Method B, renumbering the subsequent sections accordingly.

Section 22.—Change the center heading preceding this section to read: "Non-Referee Method B."

Section 23.—Change the introduction to this section to read: "The following apparatus is required." Change the note following Paragraph (*a*) to read as follows:

NOTE.—The use of a single sample tube (Section 5 (*a*)) is optional, if the appropriate procedures of Section 7(*a*) and (*b*) and Section 13(*c*) are followed.

Change the reference to "Section 5(*h*)" to "Section 5(*i*)."

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following six tentatives be approved for reference to letter ballot of the Society for adoption as standard, with revisions in four as indicated:

Tentative Methods of:

Sampling Water for Industrial Uses (D 510 - 47 T),[6] revised as follows:

Title.—Change to read: "Methods of Sampling Industrial Water."

Section 12.—Add a new Paragraph (*a*) to read as follows:

(*a*) The rate of flow shall then be regulated to not more than 500 ml. per min., after first flushing the sample line at a rate high enough to remove all sediment and gas pockets. In special cases where dissolved gases are released from solution by the drop in pressure, this should be noted on the label.

Reletter the present Paragraph (*a*) as (*b*) and delete present Paragraph (*b*).

Change Note 2 to read as follows:

NOTE 2.—The following constituents require the above precautions:

Oxygen
Total carbon dioxide
Total ammonia
Hydrogen sulfide
Free chlorine
Hardness and pH
Hydrogen
Sulfur dioxide
Ammonium
Iron
Acidity and alkalinity

Field Test for Tendency of Boiler Water to Cause Embrittlement Cracking of Steel (D 807 - 48 T),[7] with a change in title to read: "Method of Corrosivity Test of Industrial Water; (USBM* Embrittlement Detector Method)."

Corrosion Tests in Industrial Waters (NDHA Method) (D 935 - 48 T),[7] with a change in title to read: "Method of Corrosivity Test of Industrial Water (NDHA Method)."

Test for Manganese in Industrial Water (D 858 - 48 T),[7] revised by the addition of the following note to Section 7 (*a*):

> NOTE 1.—If there is evidence of manganese adhering to the sample container, it shall be dissolved with a minimum of sulfuric acid and added to the sample. Taking the original sample directly in a small container and using the entire sample for the determination of total manganese is advantageous in such cases.

Field Sampling of Water-Formed Deposits (D 887 - 48 T),[7] and

Method of Reporting Results of Chemical Analysis of Water-Formed Deposits (D 933 - 47 T).[6]

REVISION OF STANDARD, IMMEDIATE ADOPTION

Standard Method for Determination of the Chloride Ion in Industrial Waters (**D 512 - 42**)[5] and *Standard Method for Determination of the Sulfate Ion in Industrial Waters* (**D 516 - 42**).[5]—The committee recommends that these two methods be revised, as appended hereto,[8] and requests the necessary nine-tenths affirmative vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society for immediate adoption.

Standard Method of Reporting Results of Analysis of Industrial Waters (**D 596 - 46**).[5]—The committee recommends the following revisions in this standard and requests the necessary nine-tenths affirmative vote at the Annual Meeting in order that this recommendation may be referred to letter ballot of the Society for immediate adoption.

Section 2.—Add the following as a new Paragraph (*f*), relettering the subsequent paragraphs accordingly: "Total solids include both suspended and dissolved solids."

Add the following as a new Paragraph (*j*) to this section:

> (j) *Specific Electrical Conductance.*—Specific electrical conductance of an aqueous solution at a specified temperature is the reciprocal of the resistance in ohms of a cube of solution 1 cm. on edge. The specific conductance shall be expressed in micromhos per centimeter at *t* C.
>
> The actual resistance, R, of the cell is measured in ohms; the conductance, $\frac{1}{R}$, is directly proportional to the cross-sectional area, A, inversely proportional to the length of the path, l, and directly proportional to constant, L, called the specific conductance. The latter is the conductance of a cube 1 cm. on edge. Mathematically,
>
> $$\frac{1}{R} = \frac{LA}{l} \text{ or } L = \frac{l}{AR} = \frac{\text{cm}}{\text{sq. cm.} \times \text{ohms}} = \text{mhos per cm}$$
>
> The numerical value of this expression multi-

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[6] 1947 Supplement to Book of A.S.T.M. Standards, Part III-A.

[7] 1948 Supplement to Book of A.S.T.M. Standards, Part III-A.

[8] These revised methods were accepted by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 5.

plied by 1,000,000 is the specific electrical conductance in micromhos per centimeter.

Table I.—Under Chemical Tests, Miscellaneous, change: "Oily matter extractable by suitable solvents" to read: "Matter extractable with chloroform."

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[9]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II, Editorial (E. P. Partridge, chairman) edited the proposed revisions and new proposed methods originating in the other subcommittees.

Section A on the A.S.T.M. Manual on Industrial Water continues to make progress with the Manual. First drafts of most of the chapters have been prepared and reviewed but a publication date cannot be anticipated.

Subcommittee III on Methods of Sampling (Orrin M. Elliott, chairman) prepared the proposed Tentative Method of Sampling Steam referred to earlier in this report.

This subcommittee also prepared the revisions of Method D 510 and recommended the adoption as standard of Methods D 887 without revision.

The Tentative Method for Sampling Boiler Water from Stationary Boilers (D 860 - 48 T)[7] has been referred to the sponsoring subsection for a complete revision of title, technical content, and editorial form.

Work in progress and as yet not reported to the subcommittee includes proposed Methods of Test for Sampling Water at Subatmospheric Pressures. A preliminary draft includes four proposed procedures which are being studied by the subsection members.

The subsection on Specifications for Sampling Equipment reports that its studies are continuing on this assignment.

Subcommittee IV on Methods of Analysis (Frank E. Clarke, chairman) prepared the proposed Tentative Methods of Test for Acidity and Alkalinity in Industrial Waters, the Tentative Methods of Test for Iron in Industrial Water, and the Tentative Methods of Test for Suspended and Dissolved Solids in Industrial Waters, referred to earlier in this report. It submitted proposed revisions of Standard Methods D 512 and D 516. This subcommittee also prepared proposed revisions of Tentative Methods D 888 which consist of the inclusion of the requirements of an improved sample tube instead of the present requirements. This revision is based on data reported in two papers.[10] The subcommittee recommended the adoption as Standard of Tentative Methods D 858 with no revisions.

Section A on Analytical Methods has completed first drafts of proposed methods for alkali metals, for nonreferee procedure for carbon dioxide to be added to Tentative Methods D 513, for hardness, and for nitrites. Considerable progress has been made in the revision of the Tentative Methods of Test for Silica in Industrial Waters (D 859 - 47 T);[4] and the Standard Method for Determination of the Total Orthophosphate and Calculation of the Respective Orthophosphate Ions in Industrial Waters (D 515 - 43),[5] for improvement of their referee and colorimetric procedures. The section abandoned attempts to develop a method for oil in water in favor of a method for determination of matter extractable with chloroform. Consideration is being given to the desirability of developing methods of test for color and organic matter in water.

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[9] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

[10] J. F. Sebald, "An Evaluation of Test Methods for the Determination of Dissolved Oxygen in Deaerated Boiler Feedwater," *Proceedings*, Am. Soc. Testing Mats., Vol. 47, p. 1121 (1947) and J. R. McDermet, "The Determination of Dissolved Oxygen in Deaerated Boiler Feedwater," presented at the Eighth Annual Water Conference of the Engineer's Society of Western Pennsylvania, Pittsburgh, Pa. on November 13, 1947. (A limited supply of this paper is available at the Engineer's Society.)

Section B on Electrometric Methods has completed a proposed method for determination of electrical conductance.

Section C on Special Methods has made considerable progress in revising a recommended practice on X-ray diffraction examination for publication as tentative. Progress has also been made in the development of a method for detection of algae. The subsection on spectroscopy promises a proposed spectrographic procedure in the near future and the first draft of a method for polarized microscopy is being studied by that subsection.

Section D on Analysis of Deposits has completed the first draft of instructions for laboratory preparation of analytical samples. This will be incorporated in a method for complete chemical analysis of deposits. The section has been reorganized and reduced to a simple working group. It is estimated that a first draft of the analytical procedure will be ready by June, 1949.

Subcommittee V on Classification (S. K. Love, chairman) recommended minor revisions of Standard Method D 596 as given earlier in this report.

During the year the organization of the subcommittee was altered, and it now consists of two sections: (*A*) on Classification and (*B*) on Nomenclature and Terminology. The latter section has the responsibility for securing approval of definitions as may be required by all other subcommittees.

This subcommittee was assigned by the Advisory Committee to study and prepare a proposed specification for reagent grade water. This specification is intended for application of water used in chemical analysis, physical testing, and biological examination. A preliminary draft has been placed in the hands of the subcommittee members for study and comment.

Subcommittee VI on Methods of Testing (V. V. Kendall, chairman) recommended the adoption as standard of Tentative Methods D 807 and D 935. It was also recommended, for simplification of reference, that the methods be given coordinated titles, as previously given in this report.

The subsection on Substitute Ocean Water (formerly called Synthetic Sea Water) is awaiting some results of test, which will be completed this spring, before proceeding further with a specification.

The subsection on Service Testing of Pipe and Tubing has made an extensive survey of background information before proceeding with the development of specifications.

Subcommittee VII on Water-Borne Industrial Waste (L. D. Betz, chairman).—The major activity during the year was devoted to effecting the organization of this subcommittee. The subcommittee membership consists of 59 individuals and organizations. A preliminary meeting held in June, 1948, was followed by a special meeting of the subcommittee in October, 1948, at Pittsburgh, Pa. Four sections have been organized with the scopes of each section as indicated below:

The scope of Subcommittee VII on Water-Borne Industrial Waste "comprises the preparation of standard methods for sampling of water-borne industrial wastes, the preservation and analysis of samples, and the methods of reporting the results of such analyses."

The scope of Subcommittee VII is limited to water-borne waste developed or produced within an industrial establishment. This limits the activities to analysis procedures for intake and outfall water, together with various process steps within the plant.

Section A on The Critical Constituents of Water-Borne Industrial Waste whose scope is the selection of a key determination on a specific waste by which it may be evaluated.

The function of Section A is to prepare a list of the type of wastes produced by a given industry, together with the most important constituents which may be considered as typical of all plants in that industry, and hence, may be used as evaluation of such wastes as objectionable discharges. This section is considered a very important one for outlining the activities of other sections, as well as performing a highly informative and educational function for all groups or bodies dealing with the control of such wastes.

Section B on Methods of Analysis for Industrial Wastes whose scope is the preparation of all analytical methods to be used in the detection, identification, and evaluation of the components of water-borne industrial wastes.

Section C on Methods of Sampling, Gaging, and Preservation of Samples whose scope is to prepare methods of sampling, gaging of flow, and preservation of samples during the period of transportation and analysis.

Section D on Methods of Reporting Results of Analysis whose scope is to prepare methods of reporting analyses dependent upon the type of waste, etc.

Chairmen and secretaries have been appointed for each of these sections, and each will be divided into subsections for the development of specific projects.

The committee through its Subcommittees III and IV has developed methods for sampling and analysis of industrial waters. When feasible, Subcommittee VII may sponsor procedures that will fit into the published tentative and standard methods designed for use in the examination of water-borne industrial waste and they will be so specified.

This report has been submitted to letter ballot of the committee, which consists of 98 members; 77½ members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

MAX HECHT,
Chairman.

R. E. HALL,
Secretary.

REPORT OF COMMITTEE D-20

ON

PLASTICS*

Committee D-20 on Plastics and its subcommittees held three meetings during the year: in Detroit, Mich., on June 24, 1948; in Atlantic City, N. J., on November 16 and 17, 1948; and in Washington, D.C., on March 22 and 23, 1949. The Advisory Committee also met at these meetings.

The committee records with sorrow the death of two members, M. L. Macht, former vice-chairman, whose activities will long be remembered and R. W. E. Moore, who was active on a number of subcommittees.

W. C. Goggin has been appointed chairman of Subcommittee V to succeed J. H. Teeple; D. E. Northrop was appointed chairman of Subcommittee VII to succeed P. D. Brossman, and A. C. Webber as chairman of the Joint D-9 and D-20 Subcommittee on Conditioning, in place of M. L. Macht, deceased.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1948 Annual Meeting, Committee D-20 presented to the Society through the Administrative Committee on Standards the proposed Tentative Method of Test for Bond Strength of Plastics and Electrical Insulating Materials. This recommendation was accepted by the Standards Committee on July 16, 1948, and the new tentative appears in the 1948 Supplement to Book of A.S.T.M. Standards, Part III-B, as well as in the 1948 Compilation of A.S.T.M. Standards on Plastics, under the designation D 952 - 48 T.

On May 9, 1949, the Standards Committee accepted the Tentative Method of Test for Tear Resistance of Plastic Film and Sheeting. The new tentative has been assigned the designation D 1004 - 49 T. On May 13, 1949, the Standards Committee accepted two other recommendations: namely, a revision of the Tentative Method of Test for Tensile Properties of Thin Plastic Sheets and Film (D 882 - 46 T), and the addition to the Tentative Definitions of Terms Relating to Plastics (D 883 - 46 T), of definitions of the terms thermoplastic, thermoset, and thermosetting. These new and revised tentatives are appended to this report.[1]

RECOMMENDATIONS AFFECTING STANDARDS

The committee is presenting for publication seven new tentatives and is recommending the revision of ten tentatives, adoption as standard of thirteen tentatives with revisions in two of them, revision of one standard for immediate adoption, and the reaffirmation of two standards. The standard and tentatives affected, together with the revisions recommended, are listed in detail in the Appendix.

The committee has considered all of the other tentatives not mentioned in the Appendix which are under its jurisdiction and which have been issued for two years or longer and recommends that they be continued in their present status as further revisions in them are contemplated.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27-July 1, 1949.

[1] 1949 Book of A.S.T.M. Standards, Part 6.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

All of the subcommittees have been very active during the year. The Subcommittees on Specifications and on Analytical Procedures have expanded their work. The Subcommittee on Research is still attracting large attendances at its meetings.

Subcommittee I on Strength Properties (M. E. Marks, chairman).—The Section on Tensile and Compressive Strength has been very active during the year. This has resulted in the changes as given in the Appendix of the tension test (D 638) and the compression test (D 695) and a more extensive revision of the Test for Tensile Properties of Thin Plastic Sheets and Films (D 882). The Section on Tear Resistance completed the new Tentative Method of Test for Tear Resistance of Plastic Film and Sheeting (D 1004). Both the tension test and the tear test for sheets and film were prepared in cooperation with the Society of the Plastics Industry.

The falling-ball impact test has been revised and will soon be prepared for publication. The Fatigue Section has been cooperating with Committee E-9 on Fatigue. A new Section on Creep Properties has been established. A new Section on Bursting Strength has been formed to set up a method for the determination of bursting strength of laminated tubes. The Section on Shear Strength is still working on the evaluation of a double shear method. A Section on Determination of Dynamic Modulus and Damping Characteristics will be set up during the coming year. A large group attended the special meeting of the subcommittee held at the Massachusetts Institute of Technology during the last year.

Subcommittee II on Hardness (R. B. Rice, chairman).—The Method of Test for Resistance of Transparent Plastics to Surface Abrasion, appended to this report,[3] was prepared by the section on Abrasion Resistance (Optical Effects). This section is still conducting tests and studies on other abrasion methods. The Section on Abrasion Resistance (Mechanical Effects) is starting a round-robin test to formulate a method. It is expected that data on abrasive effects on plastics by water-borne sand will be available, in order that a method may be written.

Work on scratch resistance is still continuing and the Section on Rockwell Hardness Testing was reinstated for further study of the test method now in use.

Subcommittee III on Thermal Properties (E. B. Cooper, chairman) has been quite active. The flammability test for thin plastic film is being developed in cooperation with a committee of the Society of the Plastics Industry.

The new section formed last year on Postformability has made progress towards developing a test method.

A considerable amount of work is continuing on the improvement of both the Tentative Method of Test for Coefficient of Cubical Thermal Expansion of Plastics (D 864 - 45 T) and the Tentative Method of Test for Heat Distortion Temperature of Plastics (D 648 - 45 T).

During the year a new section has been set up to revise the Tentative Method of Test for Brittle Temperature of Plastics and Elastomers (D 746 - 44 T).

Subcommittee IV on Optical Properties

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[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

[3] These methods, recommended practices and definitions were accepted as tentative by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 6.

(G. W. Ingle, chairman) completed the new Tentative Method of Test for Haze and Luminous Transmittance of Transparent Plastics, appended to this report.[3] The Section on Gloss and Goniophotometry is revising the method of test for diffusion of light by plastics. Another Section is studying luminous reflectance and the transmittance characteristics and color of plastics with round-robin work still continuing.

Subcommittee V on Permanence Properties (W. C. Goggin, chairman) has been quite busy this year. A study will be made on methods for mounting films and samples for exposure to light. The method of test for weight loss of plastics on heating is under further study. The Section on Effect of Water plans to work with Committee D-6 on Paper and Paper Products on a method for measuring moisture vapor transmission. Further work will be carried on by the Section on Accelerated Service Tests. A method to measure warpage of plastic sheet intended for glazing and also a test for gas permeability of plastic will be given consideration during the year.

Subcommittee VI on Specifications (F. W. Reinhart, chairman) prepared the revisions for the Standard Specifications for Urea-Formaldehyde Molding Compounds (D 705), the Tentative Specifications for Phenolic Molding Compounds (D 700), for Polystyrene Molding Compounds (D 703), and for Laminated Thermosetting Materials (D 709) as given in the Appendix.

Revisions of a large number of other specifications for molding materials are being prepared and will be ready in the near future for letter ballot.

Specifications for cellulose propionate plastics are now being considered by a new section.

Work on polyethylene, several plasticizers, and alkyd molding materials, the latter by a recently formed section, is progressing favorably and specifications are being prepared. A new section to write specifications for base resin materials was organized.

Subcommittee VII on Analytical Methods (D. E. Northrop, chairman) completed the new Tentative Method of Test for Sampling and Testing Plasticizers Used in Plastics, appended hereto.[3] There are a number of new methods under consideration, namely, the testing of cellulose ester plastics for plasticizers as well as tests for pigment and residual solvents.

Subcommittee VIII on Research (J. D. Ryan, chairman) is continuing its work on the fundamental aspects of impact and flow properties as well as on the degradation of plastics. The subcommittee has also been continuing its function of assisting educational institutions in an advisory capacity on research problems suitable for investigation by graduate students.

At the November, 1948, meeting of this subcommittee, the following papers were presented:

"Ignition Temperatures of Plastic Materials," by J. J. Lamb, Nat. Bureau of Standards,

"Method for Weight Loss of Plastic Films and Sheets on Heating,"[4] by M. E. Marks, Pittsburgh Plate Glass Co.,

"The Significance of the Charpy and Flexure Tests in Evaluating the Impact Resistance of Plastics,"[4] by H. M. Quackenbos, Jr., J. M. Hill, Jr., and C. E. Staff, Bakelite Corp., and

"Some Notes on the Effect of Testing Machines on the Tensile Properties of Plastic Films,"[5] by L. Boor, U. S. Department of the Army, Quartermaster Corps.

After presentation of the above papers a color sound film was presented through the courtesy of the Society of the Plastics Industry showing the operation of the special universal testing machine at the Massachusetts Institute of Technology.

The subcommittee also arranged for

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[4] ASTM BULLETIN, No. 159, July, 1949, p. 53; p. 56.
[5] ASTM BULLETIN, No. 162, December, 1949, p. 47.

the following papers which were presented at its March, 1949, meeting:

"Complex Stresses in Polyethylene," by I. L. Hopkins,
"Dynamic Rheology of Polymers," by W. O. Baker, and
"Wear Resistance of Plastic Materials,"[6] by H. F. Schiefer.

Subcommittee IX on Molds and Molding (L. A. Sontag, chairman) is continuing work on molding procedures for thermosetting molding compounds as well as thermoplastic molding materials. The new Tentative Recommended Practice for Transfer Molding of Specimens of Phenolic Materials, appended hereto, was completed this year.

Revisions in the Tentative Specifications for Molds for Test Specimens (D 647) cover the addition of a new injection mold and a new transfer mold.

The Section on Transfer Dies for Test Specimens is working on a bar mold as well as a 4-in. disk mold. A recommended practice for making test specimens by an injection mold is being prepared.

A study will be undertaken to combine the Tentative Recommended Practice for Molding Specimens of Phenolic Materials (D 796 – 48 T) and the Tentative Recommended Practice for Molding Specimens of Phenolic Materials for Use in Electrical Tests (D 949 – 47 T) when adopted as standard this year.

Subcommittee X on Definitions, Nomenclature, and Significance of Test (G. W. Clark, chairman) is continuing work on definitions of additional terms besides those which are being recommended for inclusion in the Tentative Definitions of Terms Relating to Plastics (D 883 – 46 T), as appended hereto.[3]

Further consideration is being given to the publication as a tentative recommended practice comprising a code for designating form of specimen and direction of testing plastics.[7]

The subcommittee plans a revision of the Descriptive Nomenclature of Objects Made from Plastics (D 675 – 45) with the addition of pictures illustrating the visible characteristics of a plastic object.

All definitions prepared by Committee D-20 and now appearing in several methods of test will be studied with the view of combining them for publication as a part of Definitions D 883.

Joint Subcommittee, of Committees D-9 and D-20, on Conditioning (A. C. Webber, chairman).—During the past year this subcommittee has been reorganized and now includes in its membership the chairmen of all subcommittees of Committees D-9 and D-20. Activities have centered on the revision of the standard laboratory test temperature in Tentative Methods (D 618), also on further changes now under consideration.

The Tentative Method for Maintaining Constant Humidity by Means of Aqueous Solutions, as appended hereto,[3] was prepared by this subcommittee.

The subcommittee contemplates the study of the problem relating to humidity measuring apparatus, standardization of subnormal and supernormal test conditions as well as standard conditioning time.

This report has been submitted to letter ballot of the committee, which consists of 157 members; 93 members returned their ballots, of whom 86 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

G. M. KLINE,
Chairman.

B. L. LEWIS,
Secretary.

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[6] The information presented has been included in the more complete paper, "Improved Single-Unit Schiefer Abrasion Testing Machine," by H. F. Schiefer, Lawrence E. Crean, and John F. Krasny, ASTM BULLETIN, No. 159, July, 1949, p. 73.

[7] See Editorial Note, p. 487.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-20 presented to the Society through the Administrative Committee on Standards the recommendation that the Recommended Practice for Describing Form of Specimen and Direction of Testing Plastics be accepted for publication as tentative. This recommendation was accepted by the Standards Committee on September 14, 1949, and the new tentative recommended practice appears in the 1949 Book of A.S.T.M. Standards, Part 6, bearing the designation D 1009 - 49 T.

Revisions of the Tentative Specifications for Nonrigid Vinyl Chloride Plastics (D 744 - 44 T) were accepted by the Standards Committee on January 17, 1950. The revised tentative specifications appear in the 1949 Book of A.S.T.M. Standards, Part 6.

APPENDIX

RECOMMENDATIONS AFFECTING STANDARDS ON PLASTICS

In this Appendix are given a list of seven new tentatives, proposed revisions in one standard and 10 tentatives covering plastics, which are recommended as referred to earlier in this report. In addition it includes 13 tentatives recommended for adoption as standard, and proposals to reaffirm two standards. The one standard and the tentatives to be revised appear in their present form in the 1946 Book of A.S.T.M. Standards, Part III-B or its 1947 and 1948 Supplements to Part III-B, as indicated by the final number in the A.S.T.M. designation.

NEW TENTATIVES

The committee recommends the following seven new tentatives for publication as tentative, as appended hereto.[1]

Tentative Method of Test for Haze and Luminous Transmittance of Transparent Plastics:

This method is suitable for evaluating haze and for measuring light transmission through transparent plastics by new and improved equipment.

Tentative Method for Measuring Changes in Linear Dimensions of Plastics:

A suitable test method for measuring such changes using a minimum of equipment has been required for a considerable length of time and therefore this new tentative is being recommended for publication.

Tentative Method of Test for Stiffness Properties of Nonrigid Plastics as a Function of Temperature by Means of a Torsional Test:

This torsion stiffness method is being recommended for publication as tentative because of its simplicity and ease of operation where testing at low temperature is particularly desired on nonrigid plastics.

Tentative Method of Test for Resistance of Transparent Plastics to Surface Abrasion:

This abrasion method is being recommended for use on plastics used for optical surfaces. It is recommended for publication as tentative for the following reasons: (*1*) There is practically unanimous agreement that a test of this type is necessary or desirable, (*2*) this test, in essence, is being written into a code for automotive glazing materials by the American Standards Association and it is felt that it would be highly desirable for A.S.T.M. to have a similar method, and (*3*) no other suitable test for this particular property has been developed to a useful point. The committee realizes, in view of the complex nature of abrasion, that further study is necessary and it believes that such continued effort will lead to the desired improved reproducibility of test results or to the development of a better test.

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[1] These methods and recommended practices were accepted as tentative by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 6.

Tentative Methods of Sampling and Testing Plasticizers Used in Plastics:

These methods are being recommended for testing plasticizers since uniform test procedures are necessary. These methods are particularly adapted for use in sampling and testing such materials from tank cars or large vessels and other containers.

Tentative Recommended Practice for Transfer Molding of Specimens of Phenolic Materials:

There are, at present, methods for molding specimens by other means and it was felt that the transfer mold, which is quite popular, should be included.

Tentative Recommended Practice for Maintaining Constant Humidity by Means of Aqueous Solutions:

It sometimes becomes necessary to obtain relative humidities over a large range of percentages in closed containers and therefore Committee D-20 joins with Committee D-9 on Electrical Insulating Materials in submitting this recommended practice for publication as tentative.

Revisions of Tentatives

The committee recommends revisions in the following ten tentatives:

Tentative Methods of Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 – 47 T):

Committee D-20 joins with Committee D-9 in recommending that these methods be revised by changing the standard laboratory temperature in Section 2 (*a*) from "25 ± 1 C. (77 ± 1.8 F.)" to "23 ± 1.1 C. (73.4 ± 2. F.)," and in Section 2 (*c*) in the table listing the test temperatures, changing "25 C. (77 F.)" to "23 C. (73.4 F.)." This change is recommended in order to bring these methods into agreement with the requirements for a standard laboratory atmosphere as covered in the Tentative Definitions with Procedures Relating to Conditioning and Weathering (E 41 – 48 T).

Tentative Method of Test for Tensile Properties of Plastics (D 638 – 46 T):

The committee recommends the addition of the following statement on significance of test and a revision of the test procedures for rods and tubes:

New Section.—Add the following as a new Section 3 on Significance, renumbering the subsequent sections accordingly:

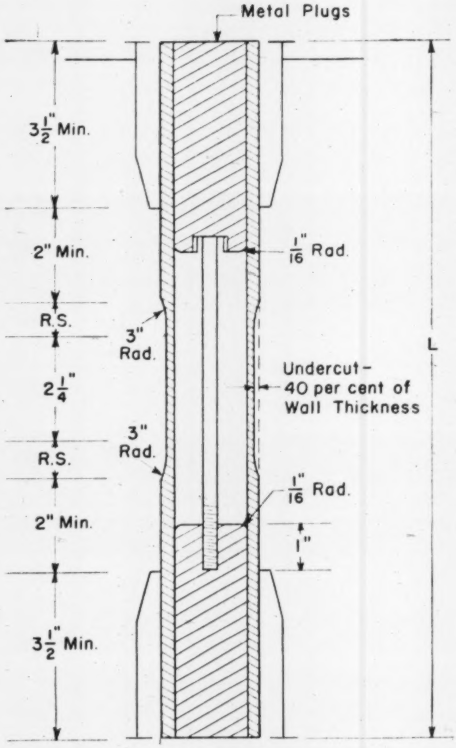
3. *Significance.*—Tension tests, properly interpreted, provide reasonably accurate information with regard to the tensile properties of plastics when employed under conditions approximating those under which the tests are made.

Tensile properties include modulus of elasticity, yield stress, elongation beyond yield point, tensile strength, elongation at break, and energy absorption. Materials possessing a low order of ductility may not exhibit a yield point. Stress-strain data at several levels of temperature, humidity, time, or other variables usually furnish reasonably accurate indications of the materials behavior.

Tension tests may provide data for research and development, engineering design, quality control, acceptance or rejection under specifications, and for special purposes. The tests cannot be considered significant for applications differing widely from the load-time scale of the standard test. Such applications require suitable tests such as impact, creep, and fatigue.

Section 4 (*b*) *and* (*c*).—Change to read as follows:

(*b*) The test specimen for rigid tubes shall be as shown in Fig. 2. The length, *L*, shall be as shown in the table under Fig. 2. A groove shall be machined around the outside of the specimen at the center of its length to a depth of 40 per cent of the nominal wall thickness. This groove shall consist of a straight section 2½ in. in length with a radius of 3 in. at each end joining it to the outside diameter. Steel or brass plugs having diameters such that they will fit snugly inside the tube and having a length equal to the full jaw length plus 1 in. shall be placed in the ends of the specimen to prevent crushing. They can be located in the tube conveniently by separating and supporting them on a threaded metal rod. Details of plugs and test assembly are shown in Fig. 2.

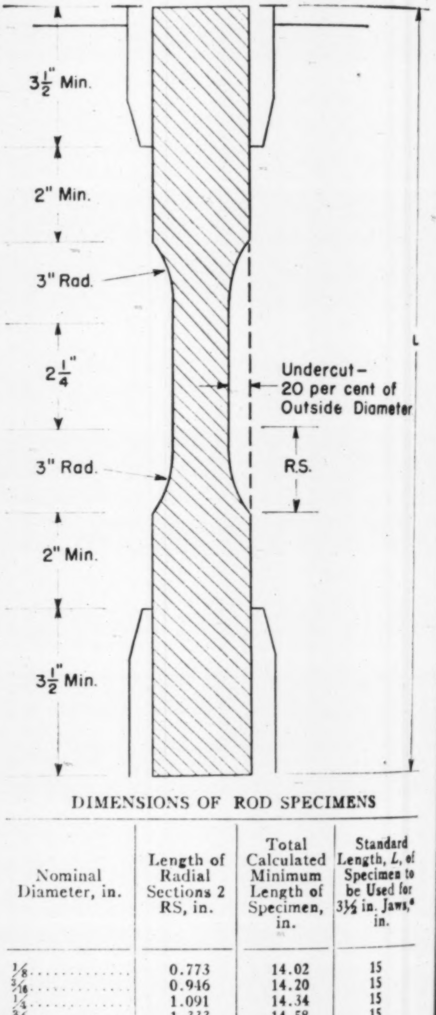

Metal Plugs
3½" Min.
2" Min.
R.S.
3" Rad.
2¼"
R.S.
3" Rad.
2" Min.
3½" Min.
1/16" Rad.
Undercut-
40 per cent of
Wall Thickness
1/16" Rad.
1"
L

DIMENSIONS OF TUBE SPECIMENS

Nominal Wall Thickness, in.	Length of Radial Sections 2RS, in.	Total Calculated Minimum Length of Specimen, in.	Standard Length, *L*, of Specimen to be Used for 3½ in. jaws,[a] in.
1/32	0.547	13.80	15
3/64	0.670	13.92	15
1/16	0.773	14.02	15
3/32	0.946	14.20	15
1/8	1.091	14.34	15
3/16	1.333	14.58	15
1/4	1.536	14.79	15.75
5/16	1.714	14.96	15.75
3/8	1.873	15.12	15.75
7/16	2.019	15.27	15.75
1/2	2.154	15.40	16.5

[a] For other jaws greater than 3½ in., the standard length shall be increased by twice the length of the jaws minus 7 in. The standard length permits a slippage of approximately ¼ to ½ in. in each jaw while maintaining maximum length of jaw grip.

FIG. 2.—Diagram Showing Location of Tube Tension Test Specimen in Testing Machine.


3½" Min.
2" Min.
3" Rad.
2¼"
3" Rad.
2" Min.
3½" Min.
Undercut-
20 per cent of
Outside Diameter
R.S.
L

DIMENSIONS OF ROD SPECIMENS

Nominal Diameter, in.	Length of Radial Sections 2 RS, in.	Total Calculated Minimum Length of Specimen, in.	Standard Length, *L*, of Specimen to be Used for 3½ in. Jaws,[a] in.
1/8	0.773	14.02	15
3/16	0.946	14.20	15
1/4	1.091	14.34	15
3/8	1.333	14.58	15
1/2	1.536	14.79	15.75
5/8	1.714	14.96	15.75
3/4	1.873	15.12	15.75
7/8	2.019	15.27	15.75
1	2.154	15.40	16.5
1¼	2.398	15.65	16.5
1½	2.615	15.87	16.5
1¾	2.812	16.06	16.5
2	2.993	16.24	17

[a] For other jaws greater than 3½ in., the standard length shall be increased by twice the length of the jaw minus 7 in. The standard length permits a slippage of approximately ¼ to ½ in. in each jaw while maintaining maximum length of jaw grip.

FIG. 3.—Diagram Showing Location of Rod Tension Test Specimen in Testing Machine.

(*c*) The test specimen for rigid rods shall be as shown in Fig. 3. The length, *L*, shall be as shown in the table under Fig. 3. A groove shall be machined around the specimen at the center of its length to a depth of 20 per cent of the original nominal diameter. This groove shall consist of a straight section 2$\frac{1}{4}$ in. in length with a radius of 3 in. at each end joining it to the outside diameter.

Tentative Specifications for Molds for Test Specimens of Molding Materials Used for Electrical Insulation (D 647 – 45 T):

A transfer type mold as well as a new injection type mold are being added. At the same time, the title and scope are being revised to meet present requirements.

Title.—Change to read as follows: "Tentative Specifications for Molds for Test Specimens for Plastic Molding Materials."

Section 1.—Change to read as follows:

1. These specifications cover the design of standard molds to be used to mold test specimens from plastic molding materials. The press and mold cycle used in molding test specimens should be agreed upon by the purchaser and the seller of the materials.

New Sections.—Add the following as new Sections 5 and 6:

5. *Mold for Injection Molding of Test Specimens:* (*a*) *Tension Specimens,* $\frac{1}{2}$ *by* $\frac{1}{8}$ *by 5 in.,* $\frac{1}{2}$ *by* $\frac{1}{4}$ *by 5 in., and* $\frac{1}{8}$ *by 2 in. in diameter.*—The mold for these specimens shall be of the design and dimensions shown in Fig. 4 and also conform to the requirements prescribed in the following Paragraphs (*b*) to (*e*):

(*b*) *Gate Sizes.*—The gate sizes shall be:

(*1*) $\frac{1}{8}$ in. in width by maximum depth of cavity,

(*2*) $\frac{1}{4}$ in. in width by maximum depth of cavity, and

(*3*) $\frac{1}{2}$ in. in width by maximum depth of cavity.

(*c*) *Tension Specimen,* $\frac{1}{2}$ *by 2 by* $\frac{1}{8}$ *in. Reduced Section.*—The cavity for the tension specimens to make specimens for the Tentative Method of Test for Tensile Properties of Plastics (A.S.T.M. Designation: D 638) shall have dimensions as shown in that test for type I specimen, except for the following:

Thickness, in.	0.125 +0.003 −0.000
Width, in.	0.500 +0.005 −0.000

(*d*) *Bar Specimens.*—The cavities for the bar specimens shall have dimensions as follows:

Length, in.	5
Thickness, in.	0.125 +0.003 −0.000
Width, in.	0.500 +0.005 −0.000

Length, in.	5
Thickness, in.	0.250 +0.003 −0.000
Width, in.	0.500 +0.005 −0.000

(*e*) *2-in. Disk Specimen.*—The cavity of the 2-in. disk shall have the following dimensions:

Diameter, in.	2
Thickness, in.	0.125 +0.003 −0.000

6. *Mold for Transfer Molding Test Specimens* $\frac{1}{2}$ *by* $\frac{1}{2}$ *by 5 in., and* $\frac{1}{4}$ *by* $\frac{1}{2}$ *by 5 in.*—The transfer mold for molding specimens $\frac{1}{2}$ by $\frac{1}{2}$ by 5 in. and $\frac{1}{4}$ by $\frac{1}{2}$ by 5 in. shall be of the design and dimensions shown in Fig. 5.

Footnote 3.—Add references to Figs. 4 and 5.

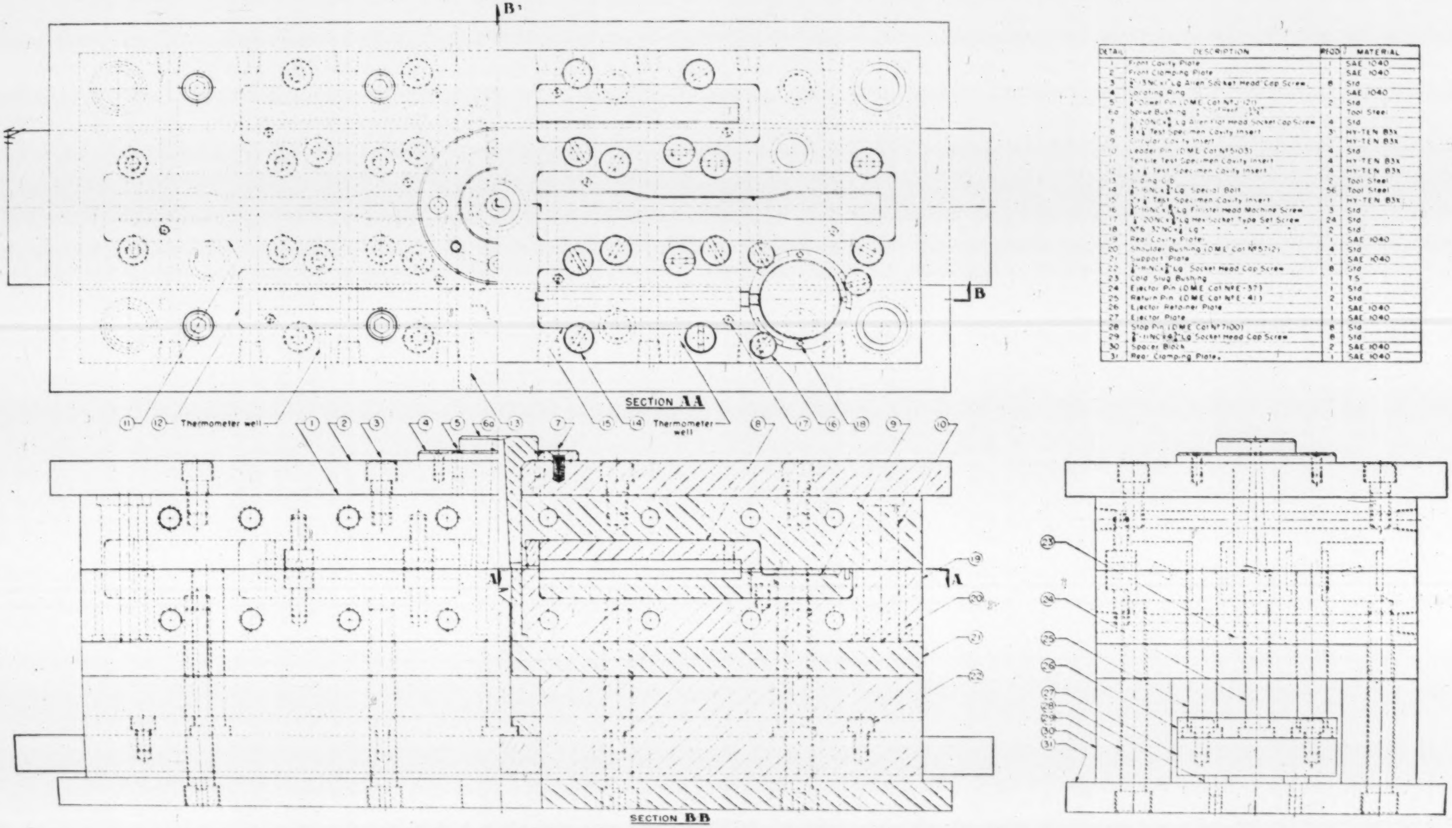
Tentative Method of Test for Repeated Flexural Stress (Fatigue) of Plastics (D 671 – 42 T):

New Section.—Add the following as a new Section 3 on significance of test, renumbering the subsequent sections accordingly:

3. *Significance of Test.*—The flexural fatigue test is expected to provide information on the ability of rigid plastics to resist the development of cracks or general mechanical deterioration as a result of a relatively large number of cycles of nearly constant amplitude-of-strain. It does not measure certain other mechanical properties such as stiffness and damping which indirectly affect the ability of a material or structure to withstand conditions tending to promote vibration.

The method is primarily a research tool which may be used for determining the effect of variations in material, stress conditions, or environmental conditions, etc., on the ability of a material to resist deterioration resulting from repeated stress. The method may also be used to provide data for use in selecting materials for service under repeated stress conditions.

The results are suitable for direct application in design only when all design factors, such as



DETAIL	DESCRIPTION	REQD	MATERIAL
1	Front Cavity Plate	1	SAE 1040
2	Front Clamping Plate	1	SAE 1040
3	½"-13NC × 1" Lg Allen Socket Head Cap Screw	8	Std
4	Locating Ring	1	SAE 1040
5	¾" Dowel Pin (DME Cat No J-121)	2	Std
6a	Sprue Bushing [illegible]	1	Tool Steel
7	¼"-20NC × ⅝" Lg Allen Flat Head Socket Cap Screw	4	Std
8	½ × ⅛" Test Specimen Cavity Insert	3	HY-TEN B3X
9	Circular Cavity Insert	1	HY-TEN B3X
10	Leader Pin (DME Cat No 5103)	4	Std
11	Tensile Test Specimen Cavity Insert	4	HY-TEN B3X
12	½ × ⅛" Test Specimen Cavity Insert	4	HY-TEN B3X
13	Sliding Gib	2	Tool Steel
14	⅜"-16NC × ¾" Lg Special Bolt	56	Tool Steel
15	½ × ⅛" Test Specimen Cavity Insert	1	HY-TEN B3X
16	⅜"-16NC × ⅝" Lg Fillister Head Machine Screw	3	Std
17	¼"-20NC × ⅜" Lg Hex Socket Type Set Screw	24	Std
18	No 6-32NC × ¼ Lg " " " "	2	Std
19	Rear Cavity Plate	1	SAE 1040
20	Shoulder Bushing (DME Cat No 5712)	4	Std
21	Support Plate	1	SAE 1040
22	⅜"-16NC × ⅞" Lg Socket Head Cap Screw	8	Std
23	Cold Slug Bushing	1	TS
24	Ejector Pin (DME Cat No E-37)	1	Std
25	Return Pin (DME Cat No E-41)	2	Std
26	Ejector Retainer Plate	1	SAE 1040
27	Ejector Plate	1	SAE 1040
28	Stop Pin (DME Cat No 7100)	8	Std
29	⅝"-11NC × 4½" Lg Socket Head Cap Screw	8	Std
30	Spacer Block	2	SAE 1040
31	Rear Clamping Plate.	1	SAE 1040

FIG. 4.—Mold for Injection Molding Tension Test Specimens.

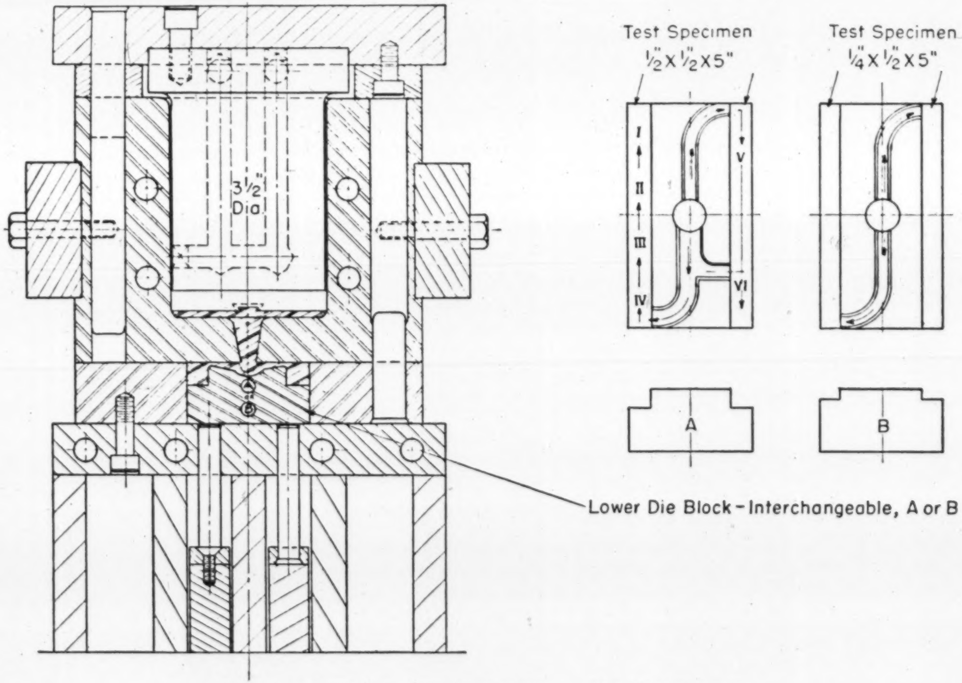

3½" Dia
Test Specimen ½" X ½" X 5"
I
II
III
IV
V
VI
Test Specimen ¼" X ½" X 5"
A
B
Lower Die Block - Interchangeable, A or B

FIG. 5.—Mold for Transfer Molding of Test Specimens.

loading, size, and shape of part, frequency of stressing and environmental conditions, closely parallel the test conditions. The test is generally unsuitable for an inspection test or quality control test, owing to the amount of time and effort required to collect the data.

The results obtained from tests made on other fatigue testing machines, other sizes and shapes of specimens, other testing speeds, etc., will usually not agree with the results obtained from this test method. The method yields results which may be reproduced within the limits of variability of the material being tested if care is taken to follow exactly the test procedure outlined and to eliminate all extraneous variables.

Tentative Method of Test for Compressive Strength of Plastics (D 695 – 44 T):

New Section.—Add the following as a new Section 3 on significance of test, renumbering the subsequent sections accordingly:

3. *Significance.*—Compression tests, properly interpreted, provide reasonably accurate information with regard to the compressive properties of plastics when employed under conditions approximating those under which the tests are made.

Compressive properties include modulus of elasticity, yield stress, deformation beyond yield point, compressive strength, (unless the material merely flattens but does not fracture), and energy-absorption (toughness). Materials possessing a low order of ductility may not exhibit a yield point. Stress-strain data at several levels of temperature, humidity, time, or other variables usually furnish reasonably accurate indications of the behavior of the material.

Compression tests may provide data for research and development, engineering design, quality control, acceptance or rejection under specifications, and for special purposes. The tests cannot be considered significant for applications differing widely from the load-time scale of the standard test. Such applications require suitable tests such as impact, creep, and fatigue.

Tentative Specifications for Phenolic Molding Compounds (D 700 – 45 T):

Committee D-20 concurs with Committee D-9 in recommending that these specifications be revised as appended hereto.[2] These specifications are being revised by the addition of two new types, 12 and 13, and the deletion of the obsolete type 1.

Tentative Specifications for Polystyrene Molding Compounds (D 703 – 48 T):

The following revision consists of changes in requirements for the designation of three types of materials. The proposed new type 1 material is essentially the same as the present type 2.

Section 2.—Change to read as follows:

2. These specifications cover the following three types of polystyrene molding compounds:

Type 1.—A general purpose compound consisting of an unmodified form of polystyrene with or without the addition of pigments and colors, as may be required, and may contain small amounts of lubricants.

Type 2.—A lubricated general-purpose compound consisting of polystyrene with or without pigments and colors, as may be required.

Type 3.—A polystyrene molding material characterized by improved heat-distortion temperature, with or without pigments and colors, as may be required.

Section 4. Revise to read as follows:

4. (*a*) *Molding Compounds.*—The compounds covered by these specifications shall conform to the following requirements:

	Type 1	Type 2	Type 3
Methanol-soluble content, max., per cent. .	3.5	5.0	3.5
Viscosity of 10 per cent solution in toluene, min., centipoises.	25*	25	20

* Changed or added requirements.

(*b*) *Molded Test Specimens.*—Test specimens ***molded by injection*** under conditions specified by the manufacturer for these three types of compounds shall conform to the requirements as to physical and electrical properties prescribed in Table I.

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[2] These revised specifications and definitions were accepted by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 6.

Table I.—Revise to read as follows:

TABLE I.—DETAIL REQUIREMENTS FOR INJECTION MOLDED TEST SPECIMENS.

		Type 1 (Formerly Type 2)	Type 2*	Type 3*
Specific gravity, 25/25 C. (77/77 F.)	max.	1.07	1.07	1.07
	min.	1.045*	1.045	1.045
Refractive index $n\frac{25}{D}$	max.	1.600	1.600	1.600
	min.	1.585	1.585	1.585
Tensile strength, min., psi.		6000*	5500	7000
Elongation in 2 in., min., per cent		1.0*	1.0	1.0
Impact strength (Izod), min., ft.-lb. per in. of notch		0.25*	0.25	0.25
Heat-distortion temperature at 264 psi. fiber stress, min:				
5 by ½ by ½-in. specimen		80 C.* 176 F.*	76 C. 169 F.	85 C. 185 F.
5 by ½ by ⅛-in. specimen		74 C. 165 F.*	70 C. 158 F.	80 C. 176 F.
Deformation under load, max., per cent		1.5	1.5	1.25
Power factor,[a] max.	60 cycles	0.0003	0.0005	0.0003
	1,000 cycles	0.0003	0.0005	0.0003
	1,000,000 cycles	0.0005	0.0010	0.0005
Dielectric constant[a]	60 cycles			
	min.	2.45	2.45	2.45
	max.	2.60	2.65	2.65
	1,000 cycles			
	min.	2.45	2.45	2.45
	max.	2.60	2.65	2.60
	1,000,000 cycles			
	min.	2.45	2.45	2.45
	max.	2.60	2.65	2.60

[a] Of uncolored, unpigmented, unfilled specimen.

* Changed or added requirements.

Tentative Specifications for Laminated Thermosetting Materials (D 709 – 48 T):

Committee D-20 concurs with Committee D-9 in recommending the following revisions to include glass-base materials:

Table I.—Add the following for a new type IV:

Type IV.
Grades G1, G2, G3, and G5.
Sheets, add reference letter *a*.

Section 4.—Add the following to the table in Note 9:

Type IV.
Grades G1, G2, G3, and G5.
Color, natural.

Table III.—Add the following requirements for type IV:

	Type IV		
	Grades G1 and G2	Grade G3	Grade G5
Tensile strength, min., psi.	7 500	17 000	20 000
Flexural strength, min., psi.	15 000	17 000	25 000
Compressive strength, min., psi. (flatwise)	33 000	38 000	50 000
Impact strength (Izod), ft-lb. per in. of width:			
Flatwise	3.5	6.0	12.0
Edgewise	3.3	5.0	5.5
Power factor at 1,000,000 cycle, max	0.032	0.035	0.020
Dielectric constant at 1,000,000 cycles, max.	5.5	6.0	7.7
Loss factor at 1,000,000 cycles, max.	0.18	0.21	0.15

NOTE.—All values are based on tests at room temperature of approximately 25 C. (77 F.). The above requirements are for sheets in thicknesses of 1/16 to 1 in., inclusive. The minimum requirements for mechanical properties for sheets from 1 to 2 in., inclusive, shall be 10 per cent lower than those given in this table.

Table IV.—Add the following requirements for type IV:

Type IV	Thickness, in.	Dielectric Strength Perpendicular to Laminations min., v. per mil	
		Short Time Test	Step-by-Step Test
Grades:			
G1 and G2	1/32 to 1/16, incl.	200	120
	Over 1/16 to ⅛ incl.	150	90
G3	1/32 to 1/16, incl.	350	210
	Over 1/16 to ⅛, incl.	275	170
G5	1/32 to 1/16, incl.	275	170
	Over 1/16 to ⅛, incl.	220	140

Table V.—Add the following requirements for type IV:

	Water Absorption After 24-hr. Immersion, max., per cent		
	Type IV		
Grade	G1, G2	G3	G5
Thickness, in.			
1/16	3.00	3.50	3.30
⅛	2.30	2.50	2.75
½	1.20	1.80	2.00

Tentative Method of Test for Flexural Properties of Plastics (D 790 – 45 T):

Committee D-20 concurs with Committee D-9 in recommending the following revisions which provide for the testing of thinner specimens than in the present method:

Section 3 (a).—Change the fourth sentence to read as follows: "The width of the specimen shall be in accordance with Table I."

Note 1.—Delete this note, renumbering subsequent notes accordingly and add a new Note 4 as follows:

NOTE 4.—The rate of crosshead motion in inches per minute for flatwise tests of 1/32-in. sheet materials may be chosen as 0.025 in. per min. to shorten the time of test.

Table I.—Change to read as follows:

TABLE I.—SUGGESTED DIMENSIONS FOR TEST SPECIMENS.

Nominal Thickness of Sheet, in.	Span, min., in.	Flatwise		Edgewise	
		Depth of Specimen, in.	Width of Specimen, in.	Depth of Specimen, in.	Width of Specimen (Nominal Thickness), in.
1/32	1/2	1/32	1	...	...
1/16	1	1/16	1	1/16	1/16
3/32	1 1/2	3/32	1	3/32	3/32
1/8	2	1/8	1	1/8	1/8
3/16	3	3/16	1/2	3/16	3/16
1/4	4	1/4	1/2	1/4	1/4
3/8	6	3/8	1/2	3/8	3/8
1/2	8	1/2	1/2	1/2	1/2
3/4	12	3/4	3/4	3/4	3/4
1	16	1	1	1	1
1 1/2	24	1 1/2	1 1/2	1 1/2	1 1/2
2	32	2	2	2	2

Section 6 (b).—Insert a reference to Note 4 at the end of this paragraph.

Add a note to this section as follows:

NOTE.—The breaking loads of certain sheet materials in 1/32-in. thickness may be lower than 60 lb. Some testing machines have poor accuracy at such loads, and it may be advisable to obtain a greater degree of accuracy by magnifying the load about 10-fold by a lever system. Details of such a lever system are given in the University of Delaware Report UD-P-12 of October 6, 1948, entitled "Flexure Testing of Thin Laminated Plastics."

Insert a reference to this note at the end of Section 2 (*a*).

Tentative Definitions of Terms Relating to Plastics (D 883 – 46 T):

The committee recommends the revision of these definitions by the addition of a number of new terms, as appended hereto.[2]

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following 13 tentatives be approved for reference to letter ballot of the Society for adoption as standard, with revisions in two as indicated:

Tentative Specifications for:

Cellulose Nitrate (Pyroxylin) Plastic Sheets, Rods, and Tubes (D 701 – 46 T),

Enclosures for Small Testing Machines for Tests at Subnormal and Supernormal Temperatures of Electrical Insulating Materials and Plastics (D 760 – 44 T), jointly with Committee D-9,

Servicing Units for Tests at Subnormal and Supernormal Temperatures of Electrical Insulating Materials and Plastics (D 761 – 44 T), jointly with Committee D-9,

Cellulose Acetate Plastic Sheets (D 786 – 46 T).

Tentative Methods of Test for:

Colorfastness of Plastics to Light (D 620 – 45 T),

Flammability of Plastics, Self-Extinguishing Type (D 757 – 44 T),

Short-Time Stability at Elevated Temperatures of Plastics Containing Chlorine (D 793 – 44 T),

Acetyl and Butyryl Content of Cellulose Acetate Butyrate (D 817 – 44 T),

Ammonia in Phenol-Formaldehyde Molded Materials (D 834 – 45 T), revised by the addition of the following new Section 2 on significance of test, renumbering the subsequent sections accordingly:

2. *Significance.*—The method is intended to give semiquantitative information regarding the free ammonia content of phenolic molded parts, as an index of the likelihood that foodstuffs and similar items in the proximity of the molded material might become contaminated with ammonia, or that metal parts might become corroded. It is not intended as an absolute measure of the free ammonia present.

Tentative Recommended Practices for:

Determining Permanent Effect of Heat on Plastics (D 794 – 44 T),

Accelerated Weathering of Plastics Using S-1 Bulb and Fog Chamber (D 795 - 44 T),
Molding Specimens of Phenolic Materials for Use in Electrical Tests (D 949 - 47 T), and
Molding Specimens of Phenolic Materials (D 796 - 48 T), with the following revisions:

Section 1.—Under each of the three headings for molding test specimens of phenolic materials, add "water absorption" to the kinds of test specimens.

Section 2(a).—Add the following as a new item (*3*):

(*3*) For molding water-absorption specimens of general purpose, mica-filled and shock-resistant phenolic molding materials, the 2-in. positive mold shown in Fig. 2 of the Tentative Specifications for Molds for Test Specimens of Plastic Molding Materials (A.S.T.M. Designation: D 647) shall be used.

New Table.—Add the accompanying new Table II:

TABLE II.—MOLDING CONDITIONS FOR WATER ABSORPTION SPECIMENS OF PHENOLIC MATERIALS.

Molding Conditions	WATER ABSORPTION SPECIMENS		
	General Purpose Phenolic Materials	Mica-Filled Phenolic Materials	Shock Resistant Phenolic Materials
Molding pressure, psi.	2500 ± 500	2500 ± 500	2500 ± 500
Molding temperature	160 ± 3 C. (320 ± 5 F.)	150 ± 3 C. (300 ± 5 F.)	150 ± 3 C. (300 ± 5 F.)
Charge	powder	powder	powder
Cure	5 min.	5 min.	5 min.
Breathing mold	yes	yes	yes

NOTE.—For the bulkier shock resistant materials it may be necessary to use preforms.

REVISION OF STANDARD, IMMEDIATE ADOPTION

Standard Specifications for Urea-Formaldehyde Molding Compounds (D 705 - 46):

The committee recommends the following revisions in these specifications for immediate adoption and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that this recommendation may be referred to letter ballot of the Society.

Section 2.—Delete grade 3 and all references to it wherever they occur.

Table I.—Delete grade 3 and change the water absorption (24-hr. immersion) maximum weight gain for grades 1 and 2 from "2.0" to "3.0" per cent. Add an arc resistance of "100 sec. minimum" for grade 1.

REAFFIRMATION OF STANDARDS

The committee recommends reaffirmation of the following two standards which have been published for six years without revision and which are to be continued as standards.

Standard Methods of Test for:

Flammability of Plastics 0.050 in. and Under in Thickness (D 568 - 43), and
Surface Irregularities of Flat Transparent Plastic Sheet (D 637 - 43).

REPORT OF COMMITTEE E-1
ON
METHODS OF TESTING*

Committee E-1 on Methods of Testing held two meetings during the year at A.S.T.M. Headquarters in Philadelphia, as follows on November 3, 1948, and April 28, 1949.

The Board of Directors of the Society has appointed Messrs. P. G. McVetty, Sam Tour, and F. D. Tuemmler each for a term of three years as members of Committee E-1.

At the November meeting the committee completed revised Regulations Governing Committee E-1 which were subsequently approved by letter ballot of the main committee as well as by the officers of the E-1 technical committees and sections.

In accordance with the new Regulations action was taken at the April meeting to reconstitute the present E-1 technical committees and sections as subcommittees. This change will be put into effect at the close of the annual meeting. The revised Regulations also provide for the appointment of Task Groups to handle specific assignments.

Task Groups:

As the result of its annual review of new areas of testing the committee decided at its April meeting to appoint task groups to review the following subjects looking toward the possibility of establishing E-1 subcommittees on these projects:

Bend Test
Shear and Torsion Tests
Thermocouples and Emf. Instruments

At the request of Committee D-11 on Rubber and Rubber-Like Materials, Committee E-1 has appointed a Task Group to review the subject of low-temperature testing of elastomeric and plastic materials. Representation will be included from Committee D-11, and Committees D-9 on Electrical Insulating Materials, and D-20 on Plastics; also special-adviser members from industry and from various Government agencies. It is hoped that the first meeting of this group may be held in June during the Annual Meeting of the Society.

Task Group on Distillation Tests (H. P. Ferguson, chairman).—This task group was appointed during the year to consider the several distillation methods and apparatus now covering by A.S.T.M. standards with a view to their further simplification and standardization. The task group is made up of representatives of the interested A.S.T.M. technical committees and will hold its first meeting in June.

Task Group on Water Vapor Permeability (Robert Burns, chairman).—A survey of methods of test in the field of water vapor permeability, transmission, etc., has been made with a view to determining possible areas of simplification. Several technical committees have expressed willingness to take part in a simplification program and have designated representatives to participate in this project. A meeting of this task group will be held in June.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends the adoption as standard of the A.S.T.M. Gas

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* Presented at the Fifty-second Annual Meeting of the Society, June 27-July 1, 1949.

Calorimeter Inlet Thermometer (50F – 47T) and the Gas Calorimeter Outlet Thermometer (51F – 47T) appearing in Tentative Specifications E 1 – 48 T.

REVISIONS OF STANDARD, IMMEDIATE ADOPTION

The committee recommends for immediate adoption the revised Specifications for A.S.T.M. Tung Oil Thermometer shown in Table I to replace those for Thermometer 32C – 44 in A.S.T.M. Standard Specifications E 1 – 47.

TABLE I.—PROPOSED REVISED SPECIFICATIONS FOR A.S.T.M. TUNG OIL THERMOMETER.

Name	A.S.T.M. Tung Oil
A.S.T.M. Thermometer	32 C–49
Liquid	mercury
Filling above liquid	nitrogen gas
Temperature range	240 to 320 C.
Subdivisions	2 C.
Total length	195 to 200 mm.
Stem diameter	6.0 to 7.0 mm.
Bulb diameter	not less than 5.0 mm. to not greater than stem
Bulb length	7.0 to 9.0 mm.
Bottom of bulb to graduation line at	Distance to 282 C. *77 to 79 mm.* Distance to 320 C *101 to 111 mm.*
Contraction chamber	[a]
Expansion chamber	[b]
Enlargement of button	[c]
Top finish	plain
Longer graduation lines at each	10 C.
Graduations numbered at each multiple of	20 C.
Immersion	total
Special marking on thermometer	ASTM TUNG
Scale error at any point when standardized, shall not exceed	1 C. at 282 C. 2 C. at any other point
Standardization	250 C., 282 C., 300 C.
Marking on case	A.S.T.M Tung Oil Thermometer 32C, 240 to 320 C.

[a] The contraction chamber shall be not less than 13 mm. below 240 C

[b] The expansion chamber or capillary extension shall permit heating to 380 C. If capillary above 320 C. is sufficiently long, expansion chamber may not be necessary.

[c] The stem shall be made with an enlargement having a diameter approximately 3 mm. greater than the diameter of the stem, the bottom of the enlargement being 150 mm. from the bottom of the bulb.

As the result of a careful study and thorough review of all the specifications for A.S.T.M. Thermometers a number of changes will be made this year in order to eliminate various minor inconsistencies and in the interest of greater simplification and standardization. While the major portion of these changes are of an editorial nature there are some which involve slight changes in substance. The committee desires to have all of these changes incorporated this year and accordingly recommends immediate revision of the Standard Specifications for A.S.T.M. Thermometers (E 1 – 47). The changes which involve substance are as follows:

Terminal Numbers.—A revision of the proposed rule governing the marking of terminal numbers in full is proposed, as follows:

> "If there are one or more numbered lines between the last full number and the terminal number, the terminal number also shall be in full.
>
> This rule need not necessarily be followed for:
>
> (*a*) Saybolt Viscosity Thermometers 17C, 17F, 18C, 18F, 19C, 19F, 20C, 20F, 21C, 21F, 22C and 22F.
>
> (*b*) Kinematic Viscosity Thermometers 28F, 29F, 30F, 44F, 45F, 46F, 47F and 48F."

Low Temperature Differentiation.—A rule is proposed also covering the use of minus signs to designate temperatures below zero. This rule is to be a part of Section 6 of the general requirements, with reference to it to be made in the table under "graduations numbered at each multiple of":

> "When a scale extends both above and below 0 C. or 0 F., the two parts of the scale shall be differentiated by some means. Examples of suitable means are:
>
> (*a*) Different colors for the two parts of the scale.
>
> (*b*) Different style of numerical characters for the two parts of the scale.
>
> (*c*) Use of minus signs before appropriate numbers below 0 C. or 0 F."

Emergent Stem Temperatures.—It is proposed to include in the tables the missing values for emergent stem temperatures as furnished by the National Bureau of Standards.

Expansion Chambers.—These are provided for in most of the thermometers and it is proposed to add them to Thermometers 1C, 1F, 4C, 4F, 12C, 12F, and 55F. A footnote regarding a permissible small enlargement at the top end of the base will be added to Thermometers 2C, 2F, 3C, 3F, and 7C.

Permanency of Range requirements of Thermometers 3C and 3F will be revised to read the same as for 8C and 8F.

Method of Specifying Expansion Chambers will be changed to the form now used for Thermometer 5C.

Limiting Range Dimensions.—Adoption of revised limiting dimensions for range position for Thermometers 1C, 1F, 4C, 4F, 9C, 9F, 10C, 10F, 11C, 11F, 12C, 12F, 14C, 14F, and 16F.

Limiting Bulb Dimensions.—Adoption of limiting bulb dimensions for Thermometers 5C, 5F, 10C, 10F, 11C, 11F, 14C, 14F, and 32C.

Redefinition of Bulb Length to read as follows: "The length of the bulb is the distance from the bottom of the bulb to the junction of bulb and stem, that is, the point where the internal bulb diameter begins to decrease as the bulb merges into the stem."

Marking on Case.—It is proposed that the A.S.T.M. Thermometer number be marked on the case.

REVISION OF TENTATIVE

The committee recommends that the same changes to eliminate minor inconsistencies as proposed above for Standard E-1 be also incorporated in the appropriate thermometers in the Tentative Specifications for A.S.T.M. Thermometers (E 1 – 48 T). In addition the following revision is recommended in the Kinematic viscosity thermometers:

> For all thermometers except the Kinematics, 28F, 29F, 30F, 44F, 45F, 46F, 47F and 48F, the scale error when standardized is specified for the entire scale. For the Kinematics, it is specified only for the test points. This is an inconsistency and should be corrected.
>
> It would be very difficult to guarantee the present tolerance of 0.10 F at all points. These thermometers are used always with corrections, therefore, it is recommended that thermometers accurate to 0.2 F. certified to 0.02 F. should be suitable for the purpose.

REAFFIRMATION OF STANDARDS

The committee recommends that the following standards be reaffirmed without change as they are considered to be up to date:

Standard Specifications for Sieves for Testing Purposes (E 11 – 39).

Standard Hardness Conversion Tables for Cartridge Brass (E 33 – 42).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[1]

REPORT OF SECTION ACTIVITIES

Section on Tension Testing (R. L. Templin, chairman).—This section held a meeting in Chicago, Ill., on March 1, 1949. During the past year the section has reviewed a number of proposed specifications involving tension testing methods and has submitted comments and suggestions to the Technical Committees responsible for the specifications. These proposed methods include tension tests of thin metallic materials, method for testing the strength properties of adhesives in shear by tension loading, elongation measurement of wire, and the interpretation of Johnson's apparent elastic limit as related to specifications for white metal bearing alloys.

There was considerable discussion of the mechanical testing of thin metallic foils in which data showing the correlation of the Mullen bursting test and tension test were considered. The need for further data was emphasized and solicited for consideration by the section.

A Task Group under the chairmanship of G. R. Gohn was appointed to review and make specific recommendations for incorporating in the Standard Methods of Tension Testing of Metallic Materials (E 8 – 47) appropriate additions to take care of tension tests of copper-base alloy rods and to consider combining certain phases of the Tentative Method of Tension Testing Steel Spring Wire (A 318 – 48 T) into Standard E 8 looking toward the elimination of additional specifications for such tests.

Section on Effect of Speed of Testing (P. G. McVetty, chairman).—This section held a meeting in Chicago on March 1, 1949. During the past year the section has collected notes on speeds actually used in the testing of a wide variety of materials and these will be included in the separate publication of the 1948 Symposium on Speed of Testing.

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[1] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

The Bibliography on Speed of Testing which was brought up to date by members of the staff of the National Bureau of Standards in 1947 is being revised by the same group with the expectation of a revision in 1950 covering references through December, 1949.

A Task Group responsible for collecting information on commercially available equipment for controlling speed of testing is continuing to provide the section with the latest information on this subject.

Active cooperation with subcommittees interested in the speed requirements for tests of various materials is continuing. An elapsed-time method of specifying speed not now included in Section 20 of Standard E 8 – 46 is being studied in several subcommittees and recommendations have been made for its consideration by the Sections on Tension and Compression Testing. A Task Group has been appointed to work with Committee E-9 on Fatigue on the effect of speed of testing for fatigue tests. Another Task Group to develop any possible general testing specification, correlating as far as possible the speed requirements of Committees D-6, D-9, D-11, D-13 and D-20, is being considered.

Section on Flexure Testing (H. F. Clemmer, chairman).—This section held no meetings this year. However, the section has been active and is expecting to complete methods of test for flexural strength of brick, refractory shapes and block-type insulating materials, and non-metallic pipe.

Section on Elastic Strength of Materials (F. M. Howell, chairman).—This section held one meeting during the year at which consideration was given to the definitions of terms contained in five specifications concerned with plastics. The differences between these definitions and those given in the Standard Definitions of Terms Relating to Methods of Testing (E 6 – 46) were considered likely to cause confusion. For that reason a joint task group made up of members of Committee D-20 on Plastics and members of this section was suggested to consider the elimination of unnecessary differences. In cooperation with Committee D-20 such a task group has been formed.

Section on Calibration of Testing Machines and Apparatus (B. L. Wilson, chairman).—At a meeting held in Chicago, on March 1, 1949, a proposed Tentative Method of Verification and Classification of Strainometers was discussed. The task group which prepared the method is giving further consideration to the proposed method in the light of this discussion.

The appointment of a task group to survey the need for work on electric-resistance wire strain gages was authorized. Changes in Tentative Methods E 4 – 47 T and E 74 – 47 T are under consideration in a task group.

Section on Softening Point (W. A. Kirklin, chairman).—The proposed consolidation of the Standard Method of Test for Softening Point of Bituminous Materials (Ring and Ball Method) (D 36 – 26) and Tentative Method of Test for Softening Point (Ball and Shouldered Ring) (E 28 – 42 T) has been generally accepted by the interested committees. Exceptions are: (*1*) Committee D-4 on Road and Paving Materials which is currently collecting data on the effect of mechanical stirring which will determine whether this feature should be included in the method for application to D-4's materials, and (*2*)

Committee D-1 whose Subcommittee XI on Resins is currently studying the application of the Ball and Ring Method to synthetic resins along with other suggested softening point methods. It now appears doubtful if the proposed consolidated method can be made ready for printing in the 1949 Book of Standards, though special effort is still being directed toward this end.

Section on Sub-Sieve Testing (C. E. Barnett, chairman).—The revision of the Tentative Method of Test for Particle Size Distribution of Sub-Sieve Size Particulate Substances (E 20 – 33 T) was accepted on September 29, 1948, by the Administrative Committee on Standards as a Tentative Recommended Practice for Analysis by Microscopical Methods for Particle Size Distribution of Particulate Substances of Sub-Sieve Sizes. It was published in Parts III-A and III-B of the 1948 Supplement to Book of A.S.T.M. Standards. Aside from the activity in connection with the acceptance of the above Recommended Practice the committee considered other A.S.T.M. procedures for the measurement of particle sizes in the sub-sieve range. These are under active review by the specific committees in charge of the methods.

Section A on Thermometers (R. M. Wilhelm, chairman).—This section held meetings on October 19, 1948, and March 8, 1949, and has been very active during the fiscal year.

After approval by Section A and confirmation by letter ballot, specifications for the following thermometers were adopted as tentative on September 29, 1948, by action of the Standards Committee: A.S.T.M. Bomb Calorimeter 56C and 56F; A.S.T.M. Tag Closed Tester, Low Range 57C and 57F; A.S.T.M. Tank Low 58F; Tank Medium 59F and Tank High 60F.

Gas calorimeter thermometers 50F–47T and 51F–47T are proposed for adoption as standard.

The special committee assigned to the investigation of inconsistencies in A.S.T.M. thermometer specifications reported on additional changes, given earlier in this report, which were approved by letter ballot.

New and revised specifications for the following thermometers are being considered: Benzene freezing point;[2] Petrolatum melting point,[2] nitrocellulose stability test.

Considerable progress has been made in the writing of specifications for a set of precision fractionally graduated thermometers. These are primarily intended for use as standards in testing thermometers but they will be available for general use in measuring temperatures to a high degree of accuracy.

Proposed methods for testing liquid-in-glass thermometers which have been under consideration for several years were approved by the Section this year and will be presented to the Society as tentative through the Standards Committee later in the year.[2]

Section on Conditioning and Weathering (Robert Burns, chairman).—This subcommittee has completed a revision in the Tentative Definitions with Procedures Relating to Conditioning and Weathering (E 41 – 48 T) which specifies the standard laboratory atmosphere as that having a relative humidity of 50 ± 2 per cent at a temperature of 23 ± 1.1 C. (73.4 ± 2 F.). This revision was approved by the Society and is published in the 1948 Supplement to Book of Standards.

A tabulation of requirements for conditioning and weathering appearing in A.S.T.M. standards is being prepared by the Secretary. The subcommittee plans to inform the responsible technical committees of instances of overlapping or duplication and to inaugurate procedures leading to their elimination.

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[2] See Editorial Note, p. 503.

This report has been submitted to letter ballot of the committee, which consists of 12 members; 12 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

J. R. TOWNSEND,
Chairman.

P. J. SMITH,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee E-1 presented to the Society through the Administrative Committee on Standards the following recommendations:

New Tentative Methods of:

Testing and Standardization of Etched Stem Liquid-in-Glass Thermometers (E 77 – 49 T), and Compression Testing of Metallic Materials in Sheet Form (E 78 – 49 T).

Revision of Tentative Specifications for:

A.S.T.M. Thermometers (E 1 – 48 T).

Revision of Tentative Methods of:

Compression Testing of Metallic Materials (E 9 – 46 T).

These recommendations were accepted by the Standards Committee on September 22, 1949. Tentative Specifications E 1 and Tentative Methods E 77 appear in the 1949 Book of A.S.T.M. Standards, Parts 3, 4, 5, and 6, and Tentative Methods E 78 and E 9 in Parts 1 and 2 of the 1949 Book of A.S.T.M. Standards.

REPORT OF COMMITTEE E-2
ON
SPECTROGRAPHIC ANALYSIS*

Committee E-2 on Spectrographic Analysis held one meeting during the past year at Detroit, Mich., on June 21 and 22, 1948, with 46 members attending. Meetings of all subcommittees and of the Advisory Committee were held at this time. Meetings of the Advisory Committee also were held at Detroit, Mich., on October 22, 1948, and at Pittsburgh, Pa., on February 18, 1949.

The membership of the committee is now 106, representing a net gain of 4 members over last year.

The committee will recommend at a later date to the Administrative Committee on Standards the withdrawal of the Tentative Method of Quantitative Spectrochemical Analysis of High Grade Pig Lead (E 25 – 37 T) and the Tentative Method of Spectrochemical Analysis of Lead Alloys for Minor Constitutents and Impurities (E 49 – 43 T).[1]

TENTATIVES CONTINUED WITHOUT REVISION

Committee E-2 recommends that the following three tentatives be retained as tentative without revision:

Tentative Method of:

Spectrochemical Analysis of Zinc for Lead, Iron, and Cadmium (E 26 – 43 T),

Spectrochemical Analysis of Zinc-Alloy Die Castings for Minor Constituents and Impurities (E 27 – 43 T), and

Spectrochemical Analysis of Tin Alloys for Minor Constituents and Impurities (E 51 – 43 T).

Because of the primary interest of the present members of Committee E-2 in emission spectroscopy, the committee recommends that references to absorption technique and color spectroscopy be deleted from the scope of the committee, and further, that an independent A.S.T.M. committee be established for the growing field of absorption spectroscopy. Committee E-2 accordingly recommends the following as its name and scope:

> Committee E-2 on Emission Spectroscopy
>
> *Scope.*—The formulation of methods of spectroscopic analysis by emission techniques.

The committee expects to cooperate in every way possible with the work of the proposed committee on absorption spectroscopy and the other interested committees including the Joint Committee on Nomenclature in Applied Spectroscopy and Committee E-3 on Chemical Analysis of Metals. Close cooperation of these committees would appear to be essential to avoid overlapping of activities and to promote progress in the preparation of analytical methods.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Apparatus and Equipment (R. W. Callon, chairman) presented the final draft of a report on Location, Installation, and Safety Precautions for the Spectrographic Laboratory. A preliminary report on the specification of spectrographic apparatus was prepared. A cooperative study on the quality of photographic materials has progressed to the testing of an experimental emulsion by members of the group.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] See Editorial Note, p. 505.

Subcommittee II on Fundamental Methods (E. B. Ashcraft, chairman) presented a report on the specification of excitation sources involving the statement of important parameters affecting spark excitation and describing means of measuring the parameters. A report on measurements of precision is in preparation.

Subcommittee III, Editorial (C. L. Guettel, chairman).—The second progress report on Nomenclature in Applied Spectroscopy was distributed to members of Committee E-2 and others. Suggested methods of analysis, totaling 21, were reviewed editorially, and 7 additional methods are in course of review.

Subcommittee IV on Standards and Pure Materials (C. H. Corliss, chairman) has prepared a survey of available high-purity materials which are particularly useful to spectrographic analysis.

Subcommittees V, VI, VII, VIII, IX, and X are engaged in the revision and review of the 38 suggested analytical methods now on hand. It is expected that approximately 25 of the methods will be completed in proper form and submitted for publication by the Society during the coming year. Included in this compilation are methods covering copper alloys, pure copper, cathode nickel (at the request of Committee E-4 on Metallography), lead, lead alloys, aluminum and its alloys, zinc and cadmium and zinc-base die casting alloys, low-alloy steel and cast irons, and nonmetallic materials—the latter including ten methods on refractories, cement, and salts, such as silver nitrate.

This report has been submitted to letter ballot of the committee, which consists of 106 members; 80 members returned their ballots, of whom 73 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

B. F. SCRIBNER,
Chairman.

MARY E. WARGA,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee E-2 presented to the Society through the Administrative Committee on Standards the following recommendations:

Withdrawal of Tentative Methods of:

Quantitative Spectrochemical Analysis of High Grade Pig Lead (E 25 - 37 T), and
Spectrochemical Analysis of Lead Alloys for Minor Constituents and Impurities (E 49 - 43 T).

These recommendations were accepted by the Standards Committee on November 15, 1949.

REPORT OF COMMITTEE E-3

ON

CHEMICAL ANALYSIS OF METALS*

Committee E-3 on Chemical Analysis of Metals held two meetings during the year: at Detroit, Mich., on June 25, 1948, and at Pittsburgh, Pa., on January 19, 1949. In addition, divisional and subcommittee meetings were held in Detroit, Philadelphia, Pittsburgh, Newark, and Waterbury. Also, there have been several meetings of informal groups to discuss specific problems. The important work of the committee is done through the subcommittees and task groups and by the cooperation of individuals between meetings. Activities on the development or revision of methods for inclusion in the A.S.T.M. Methods of Chemical Analysis of Metals, are being intensified, looking forward to a new edition of the book.

With the election of D. R. Evans to the chairmanship of the main committee, Clarence Zischkau was elected chairman of the Non-Ferrous Division to fill the unexpired term.

The Advisory Committee held two important meetings: on June 25, 1948, in Detroit, and on January 18, 1949, in Pittsburgh. This committee not only coordinates the activities of the divisions but recommends the broad policies and objectives for the committee. Along these lines the Advisory Committee has received and carefully considered several suggestions for improving the procedures followed in the organization and activities of the committee. Some of these suggestions have been approved and are being put into effect as indicated below.

The Advisory Committee approved the policy of having the description of an apparatus used in only one place, included in the method in which it is used and not in the Recommended Practices for Apparatus and Reagents for Chemical Analysis of Metals (E 50).

The plan of designating the divisions of Committee E-3 by the first letters of the alphabet has led to conflicts with similar designations for the technical committees of the Society; therefore, the Advisory Committee has approved new designations as follows: Division F, Ferrous Division; Division N, Non-Ferrous Division; Division S, Sampling Division; and Division G, General Analytical Division.

The By-laws of Committee E-3 have been amended by approval through a letter ballot to provide for each division a vice-chairman who will assist the chairman and will be available to substitute for him when desired.

The Advisory Committee approved the following as the scope of Committee E-3 in the matter of sampling. After the appropriate specification committee has decided how the gross sample shall be taken and how many pieces shall be taken from a lot, Division S of Committee E-3 will cover the preparation of the sample for analysis from this point. General sampling procedures will be included in the A.S.T.M. Methods of Chemical Analysis of Metals, and specific sampling procedures will be included in the specification for the particular material.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

The Advisory Committee accepted the policy of having methods for the analysis of metal powders for metallurgical purposes handled by Committee B-9 on Metal Powders and Metal Powder Products through Committee E-3. When applied to pigment uses, methods for the analysis of metal powders will be handled through a pigment committee.

Committee E-3 is sponsoring a symposium on quick identification tests, of which spot tests are one example, at the 1949 Annual Meeting of the Society.

The editorial subcommittee held two meetings during the year: one on June 24, 1948, in Detroit and one on October 29, 1948, in Philadelphia. On the election of D. R. Evans to the chairmanship of Committee E-3, S. E. Q. Ashley was named chairman of the editorial subcommittee.

The editorial subcommittee decided on a procedure by which photometric methods, now in a separate section of the A.S.T.M. Methods of Chemical Analysis of Metals, will be moved and inserted adjacent to other methods for the same material but not included within these methods.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1948 Annual Meeting, Committee E-3 presented to the Society through the Administrative Committee on Standards the recommendation that additional Recommended Practices for Apparatus for Chemical Analysis of Metals be accepted for publication as a tentative revision of Recommended Practices E 50 – 48. This recommendation was accepted by the Standards Committee on September 29, 1948, and the new tentative has been assigned the designation E 50 – 48 T.

The proposed Tentative Methods for the Analysis of Copper-Nickel and Copper-Nickel-Zinc Alloys were accepted as tentative by the Standards Committee on May 9, 1949, and have been assigned the designation E 75 – 49 T.

ADOPTION OF TENTATIVES AS STANDARD

Committee E-3 recommends that the following three tentatives be approved for reference to letter ballot of the Society for adoption as standard, two without revision and one with revisions as indicated:

Tentative Methods of Chemical Analysis of:

Special Brasses and Bronzes (E 54 – 46 T),
White Metal Bearing Alloys (E 57 – 46 T), and
Lead- and Tin-Base Solder Metal (E 46 – 46 T), revised by the deletion of Section 16 (*h*) to (*j*) and the inclusion instead of a footnote reference to the Tentative Photometric Method for Determination of Iron in Lead- and Tin-Base Alloys (E 67 – 46 T).

REVISIONS OF STANDARDS, IMMEDIATE ADOPTION

Committee E-3 recommends revisions for immediate adoption in the following two standards and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society.

Standard Methods of Chemical Analysis of:

Aluminum and Aluminum-Base Alloys (E 34 – 45), revise by deleting Sections 10 to 15, which cover visual colorimetric methods for determining iron and titanium subject to completion of new tentative photometric methods for these elements. Also delete Sections 24 to 26 covering the bismuthate procedure for manganese, since Methods E 34 also include a persulfate method which is more generally used, and a photometric method for manganese will soon be completed.

Magnesium and Magnesium-Base Alloys (E 35 – 45), revise by deleting Sections 31 to 33 and 36 to 41 which cover visual colorimetric methods for silicon and iron. Insert, instead, footnote references to Sections 25 to 31 and 11 to 24, respectively, of the Tentative Photometric Methods for Chemical Analysis of Magnesium and Magnesium-Base Alloys (E 61 – 46 T), which cover photometric procedures for the same elements.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the remaining tentatives which have stood for two years or more without revision be retained in their tentative status for further study.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[1]

ACTIVITIES OF DIVISIONS AND SUBCOMMITTEES

Division F on Ferrous Metals (Arba Thomas, chairman) held two well-attended meetings during the year: one at the Annual Meeting of the Society on June 24, 1948, at Detroit, and another in Pittsburgh on January 19, 1949.

The main subject of discussion at both meetings was the revision of the methods published in the 1946 edition of the Book of A.S.T.M. Methods of Chemical Analysis of Metals. The subgroups responsible for these revisions have given the problem considerable study, and it appears that in many instances rapid photometric methods may be considered for replacing some of the present time-consuming volumetric and gravimetric procedures. The task groups will probably not be able to give these new methods sufficient analytical study so that they can be incorporated in the next edition of the book; however, all necessary modifications of the published methods will be made before the next edition.

The present published tentative combustion sulfur method has been subjected to considerable criticism by analysts who have tried out the procedure on plain carbon, low-alloy steels, and cast iron in that the method as written does not overcome the objectionable iron oxide fog that forms during the combustion of these materials, especially cast iron. This is a valid criticism as the deposition of the iron oxide in the cooler portion of the combustion tube at the exit end makes the use of a constant factor impossible. The method, as written, however, is entirely satisfactory for high-alloy steels of the stainless types. The insertion of a porous, ceramic filter in the hot combustion zone may eliminate this difficulty, and certain members of the Division are collecting data on this point.

The subgroup responsible for a method for beryllium in steel has completed its work and has submitted the proposed procedure to the Editorial Committee and Division G for their comments and criticisms. It is expected that by the June, 1949, meeting this method will be ready for letter ballot.

The subgroup responsible for a method for tin in steel has also completed its work, and the proposed procedure and supporting analytical data will be sent to the Editorial Committee and Division G for their comments and criticism. It is hoped that this proposed method will be ready for letter ballot by the June, 1949, meeting.

The subgroup in charge of the development of a method for the determination of aluminum in stainless steels has not yet completed its work. It is expected, however, that by the June, 1949, meeting this subgroup will have made sufficient progress so that it can recommend a satisfactory method.

The subgroup developing a method for the determination of zirconium in alloys containing tungsten and cobalt has experienced considerable difficulty, and more time is needed before a satisfactory method will be forthcoming.

All task forces or subgroups and standing committee chairmen have been requested to write up all proposed new methods and revised published methods with supporting analytical data in standard editorial form in order to expedite the submission of the methods to letter ballot by the Division and Committee E-3.

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[1] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

The question of whether the Methods for Chemical Analysis of Steel (E 30) are applicable to malleable iron has been raised by Committee A-7 on Malleable-Iron Castings. It is the concensus of the Division that practically all of the latest edition of E 30 methods are applicable to malleable iron. This question will receive further consideration at the June, 1949, meeting.

The Method for the Sampling of Ferro-Alloys (E 32 – 42) is being reviewed with the intention of expanding its scope to include the sampling of ferro-boron and ferro-titanium.

John J. Furey was appointed chairman of standing Subcommittee F-1 (Ferro-Alloys) replacing T. R. Cunningham who resigned from the Division. Also, H. Kirtchik was appointed Chairman of standing Subcommittee F-2 (Electrical Heating Alloys) replacing Mr. Cunningham.

Mr. T. R. Cunningham has been elected an honorary consulting member of Division F.

Division N on Non-Ferrous Metals (Clarence Zischkau, acting chairman) held meetings at Detroit during June, 1948, and at Pittsburgh in January, 1949.

During the year H. V. Churchill withdrew as chairman of Subcommittee N-3 which covered aluminum and magnesium and their alloys. This subcommittee has since been replaced by two subcommittees, one on aluminum and its alloys and the other on magnesium and its alloys.

Subcommittee N-1 on Copper and Its Alloys (R. P. Nevers, chairman) held a meeting in June, 1948, at Detroit at which the main subject of discussion was the Proposed Tentative Methods of Analysis of Copper-Nickel and Copper-Nickel-Zinc Alloys. Special task group meetings were held at Waterbury and Newark and the final draft was agreed upon at the January Meeting at Pittsburgh. This method has since been accepted by the Standards Committee as mentioned earlier in this report.

The present program calls for development of methods for the determination of sulfur and small amounts of aluminum in special brasses and bronzes and also for methods of analysis for copper-beryllium alloys.

Subcommittee N-2 on Lead, Tin, Antimony, Bismuth, and Their Alloys (C. L. Luke, chairman) was relatively inactive during part of the year. Proposed methods are under consideration covering the analysis of antimony metal. Two samples are to be submitted to members cooperating in this work with the hope that data and methods will be discussed at the annual meeting in June.

Methods are being prepared for the photometric determination of copper, bismuth, arsenic, iron, and zinc in pig lead. Two samples will be submitted to the active members of the committee in time to obtain some data for presentation at the coming annual meeting.

Subcommittee N-3 on Aluminum and Its Alloys (K. C. Braun, chairman).—The main activity of this committee during the year has been the cooperation with Subcommittee N-7 in devising photometric methods for copper, nickel, iron, chromium, manganese, and titanium. These methods are in the process of being submitted to letter ballot.[2]

Methods E 34 are under review and the method for silicon, using sodium hydroxide for decomposition and perchloric acid for dehydration, will be investigated for possible modification.

Contemplated work for the future is to develop methods for the determination of small amounts of lead, bismuth, and zinc.

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[2] See Editorial Note p. 512.

Subcommittee N-4 on Zinc and Its Alloys (R. K. Bell, chairman).—The present methods have been reviewed during the year with an earnest attempt to make improvements. No new methods have been submitted in that it was felt that future work will be along lines of instrumentation.

The program to be considered in this committee will be the investigation of the application of photometric methods for the determination of certain elements.

Subcommittee N-6 on Nickel and Its Alloys (Calvin Sterling, chairman).—No cooperative work has been accomplished since the last annual meeting. Mr. Potter has agreed to form a task force to work on electronic nickel. The present program calls for cooperative work on nickel-copper alloys and draft methods and samples are being prepared.

Subcommittee N-7 on Photometric Methods (R. G. Ernst, chairman).—The activities of this subcommittee for the past year may be listed as follows:

(*1*) Preparation, revision, testing, editing, and accumulation of cooperative data on methods for the analysis of aluminum-base alloys. There are six such methods now ready for distribution for letter ballot.

(*2*) Development work on a method for the analysis of silicon in copper-base alloys. This is an attempt to make an existing method applicable to any and all possible copper-base alloys and is as yet uncompleted.

(*3*) A method for the treatment of blanks in photometric analyses is being considered in connection with its applicability to the many differing specific cases that have arisen or may arise in A.S.T.M. methods.

This committee will continue to cooperate with the other committees on photometric work.

Subcommittee N-8 on Polarographic Methods (W. W. Braun, chairman).—Proposed methods for the determination of certain elements in antimony metal are under consideration. Methods are in preparation for some of the impurities in pig-lead.

Subcommittee N-9 on Magnesium and Its Alloys (V. A. Stenger, chairman) held one meeting in January at Pittsburgh since it was created by the division of the former Subcommittee B-3 in December, 1948. Work in progress centers around collaboration with the National Bureau of Standards in the preparation and analysis of a standard magnesium-base alloy.

A photometric method for nickel in the range of 1 to 10 ppm. is needed and work in this direction is being planned. There would also be use for a photometric aluminum method in the range of 2 to 10 per cent.

Division S on Sampling (W. C. Bowden, Jr., chairman) has held two meetings during the year: on Thursday, June 24, 1948, in Detroit, and on January 18, 1949, in Pittsburgh.

The procedures for the sampling of pig lead and antimony metal were written in cooperation with Subcommittee II of Committee B-2 on Non-ferrous Metals and Alloys. The procedure for sampling of pig lead is being submitted as a revision for immediate adoption in the Standard Specifications for Pig Lead (B 29 – 43) by Committee B-2.[3] The procedure for the sampling of antimony metal is being submitted as a new tentative specification by Committee B-2.[3]

The cooperating task forces of Committees E-3 and B-5 on Copper and Wrought Alloys have held several meetings, and work is progressing satisfactorily. Division S has supplied Committee B-5 with the requisite sample sizes for the various specifications, and these figures will be used in proposed revisions of sampling procedure.

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[3] 1949 Book of A.S.T.M. Standards, Part 2.

Messrs. Barry and Nevers have been appointed as a task group to write a method for sampling cast non-ferrous metals and alloys, and it is hoped this will be ready for consideration at the Annual Meeting. It is to supplement the Standard Method of Sampling Wrought Non-Ferrous Metals and Alloys for Determination of Chemical Composition (E 55 - 48), and the plans are that the specification committees will refer to it and the proposed new methods when writing future specifications.

Committee A-9 on Ferro-Alloys has prepared specifications for ferro-titanium and ferro-boron, and Division S is cooperating with Committee A-9 in the preparation of methods of sampling these ferro-alloys.

Division G—General Analytical Division (S. E. Q. Ashley, chairman) is primarily responsible for the correlation of the analytical procedures developed in the other divisions of Committee E-3 and for recommending the use of some of the newer analytical techniques, where applicable. In line with these policies, the subcommittees of Division G have been reviewing the analytical procedures under the supervision of Committee E-3.

Subcommittee G-1 on the Development, Preparation, or Standardization of Reagents (T. C. Bryson, chairman) has tabulated the reagents required for the analytical procedures and will provide uniform descriptions of these reagents. This committee has also been considering safety precautions applicable to procedures under the jurisdiction of Committee E-3.

Subcommittee G-2 on the Development and Standardization of Apparatus (Thomas L. King, chairman) completed the preparation of the Tentative Recommended Practice E 50, referred to earlier in this report, which comprises the requirements for apparatus for detecting the dead-stop end point and revisions in the requirements for the mercury cathode cell and the apparatus for potientiometric titration. Consideration has been given to specifications for filter papers in cooperation with Committee D-6 on Paper and Paper Products and to performance specifications for analytical balances.

Subcommittee G-3 on Common Procedures (J. H. Harley, chairman) has completed a compilation of those procedures which are common to two or more methods and is taking steps to resolve differences between them.

Subcommittee G-4 on Precision and Accuracy of Methods for the Analysis of Metals (Grant Wernimont, chairman) has been relatively inactive but has in preparation recommended practices for the use of statistical methods in analytical work.

This report has been submitted to letter ballot of the committee, which consists of 100 members; 81 members returned their ballots, all of whom voted affirmatively.

Respectfully submitted on behalf of the committee,

D. R. EVANS,
Chairman.

J. W. STILLMAN,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee E-3 presented to the Society through the Administrative Committee on Standards the following recommendations:

New Tentative Photometric Method for:

Determination of Cobalt in Nickel (E 39-49 T), and
Analysis of Aluminum-Base Alloys: Determination of Chromium, Copper, Iron, Manganese, Nickel and Titanium (E 34-49 T).

These recommendations were accepted by the Standards Committee on September 22, 1949.

REPORT OF COMMITTEE E-4
ON
METALLOGRAPHY*

Committee E-4 on Metallography and a number of its subcommittees held meetings during the spring meetings of the Society at Chicago, Ill., on Feb. 28 and March 1, 1949.

In addition to the above, a meeting was held with the representative of an active electron microscope group working on metals. This group has since decided to join their efforts with Committee E-4. At the meeting of Committee E-4 in June, 1949, it was voted to establish the group as a new Subcommittee XI on Electron Microstructure of Steels. The resulting consolidation should be mutually advantageous and provide the Society with an already formed group which is conducting a very constructive program correlating optical and electron microscopy on identical metal samples. The establishment of still another new Subcommittee was decided at the June meeting. This group is to be Subcommittee III (P. A. Beck, chairman) on Nomenclature. It will have the responsibility of determining the logical and proper nomenclature for alloy phases in binary and more complex alloy systems.

Committee E-4 has been enjoying a slow but steady growth and has now attained a total of 86 members.

NEW TENTATIVES

The committee is preparing proposed Tentative Methods of Classification of Ferrite Grain Size in Steels which will be submitted later to the Administrative Committee on Standards for publication as a new tentative. These methods are a revision of the grain size standard now in Tentative Methods E-2 incorporating recommendations concerning the relationship between the grain size measurements of various non-ferrous metals and alloys.

The following new tentatives have been prepared and were approved by unanimous vote at the annual meeting of Committee E-4:

Proposed Tentative Methods for Estimating the Average Grain Size of Wrought Copper and Copper-Base Alloys,
Proposed Tentative Recommended Practice for Dilatometric Analysis of Metallic Materials,
Proposed Method for Determining the Orientation of a Metal Crystal, and
Proposed Method for Preparing Quantitative Pole Figures of Metals.

REVISION OF TENTATIVE

The committee recommends that the Tentative Methods of Preparation of Micrographs of Metals and Alloys (Including Recommended Practice for Photography as Applied to Metallography) (E 2 - 44 T) be revised as appended hereto.[1]

REAFFIRMATION OF STANDARDS

The committee recommends reaffirmation as standard of the Standard Definitions of Terms Relating to Metallography (E 7 - 27)[2] and the Recommended Practice for Thermal Analysis of Steel (E 14 - 33).[3]

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* Presented at the Fifty-second Annual Meeting of the Society, June 27-July 1, 1949.

[1] These revised methods were accepted by the Society and appear in the 1949 Book of A.S.T.M. Standards, Part 2.

[2] 1946 Book of A.S.T.M. Standards, Part I-B.

[3] 1946 Book of A.S.T.M. Standards, Part I-A.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following three tentatives be continued in their present status without revision:

Tentative Methods of:

Preparation of Metallographic Specimens (E 3 - 46 T).[2]

Tentative Recommended Practices for:

Identification of Crystalline Materials by the Hanawalt X-Ray Diffraction Method (E 43 - 46 T),[2] and

Determining the Inclusion Content of Steel (E 45 - 46 T).[3]

The recommendations appearing in this report have been submitted to letter ballot of the committee the results of which will be reported at the Annual Meeting.[4]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Selection and Preparation of Samples (J. R. Vilella, chairman) reviewed Tentative Methods E 3 - 46 T and recommended that they be continued as tentative without change.

Subcommittee II on Definitions (P. A. Beck, chairman) was reinstated last year and held its first meeting in its present form on March 1, 1948, in Washington, D. C. At that meeting, it was decided to subdivide the field of work of the subcommittee into the following 12 sections: (*1*) Optical Microscopy; (*2*) X-Ray Diffraction; (*3*) Photography; (*4*) Grain Size; (*5*) Alloy Structures (Ferrous); (*6*) Alloy Structures (Non-ferrous); (*7*) Inclusions; (*8*) Thermal Analysis; (*9*) Microradiography; (*10*) Powder Metallurgy; (*11*) Electron Microscopy; (*12*) Electron Diffraction. Appointments were made and accepted immediately for the various task groups to handle the work of each section, excepting Sections 11 and 12, which so far have been inactive. Since a new Subcommittee XI on Electron Microstructure of Steels was established by action taken at the June, 1949, meeting, Section 11 will soon become active.

In correspondence during the following year the various task groups completed their assignments and prepared for each section tentative lists of terms to be defined and abbreviated. At the second meeting of the subcommittee, on March 1, 1949, all of these tentative lists, amounting to a total number of approximately 450 terms, were reviewed by the members of the subcommittee. At this time, Sections 8, 9, and 10 were the only ones whose assignment was incomplete. Since that meeting, the terms on powder-metallurgy have been received.

The assignments of the other missing sections were completed and processed by the subcommittee and the combined list of terms was accepted at the Annual Meeting. Work in defining the terms has been initiated and will continue throughout the coming year.

The subcommittee has recommended the continuation of Standard Definitions E 7 despite their antiquity and plans to have a complete and modern list of definitions to replace them by next year.

Subcommittee IV on Photography (L. V. Foster, chairman) held a meeting in Chicago, Ill., on February 28, 1949, at which it was reported that the Symposium on Metallography in Color is almost ready for publication.[5]

This subcommittee prepared the revisions of Tentative Methods E 2, referred to earlier in this report.

Subcommittee V on Microhardness (Alexander Gobus, chairman) held its first meeting on March 2, 1948. It was, in general, a fact-find session, to determine what the experience of testers has been and what must be accomplished in order to establish standards or recommended practices.

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[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at A.S.T.M. Headquarters.

[5] Published, in December, 1949.

The discussion developed some interesting opinions, several of which are presented as follows:

1. Cast iron and ingot iron do not give reproducible hardness results at high loads.
2. Dead weight loading is reproducible, spring loading is not as reliable.
3. Indention at low load may be better interpreted if a scratch is also made and studied.

At a meeting on June 21, 1948, other troublesome factors were developed. It was said that due to waviness, electrolytic polishing was not satisfactory. It was indicated that orientation of the impression has been found to change the apparent hardness up to 28 per cent.

Probable errors were felt to be:

1. Calibration of stage micrometer.
2. Characteristic dimensions of diamond.
3. Levelness.
4. Loading accuracy of tester.
5. Specimen preparation.
6. Errors in optical system.
7. Backlash in filar.
8. Location of mythical image.

It was decided that the greatest error thus far encountered was due to the fact that the stage micrometers used in calibrating filars possess a prohibitive inaccuracy. It has been learned that the Bausch & Lomb Co. believes it will soon be in a position to furnish a stage micrometer with an accuracy of 0.1 μ.

It developed that the Bureau of Standards could not rapidly certify such stage micrometers but that R. D. France at the Frankford Arsenal may be able to arrange for such a service.

Just as soon as the stage micrometer question has been solved the committee will circulate test blocks to various testers to determine what further errors must be eliminated and what order of importance they occupy.

Subcommittee VI on X-Ray Methods (W. L. Fink, chairman) has reviewed the Tentative Recommended Practice E 43 but is recommending no changes at this time. The Joint Committee on X-Ray Diffraction has the new editions of the card indexes nearly ready for the press. This new edition will probably be printed on cards which will permit mechanical sorting to be used.

A Proposed Tentative Method for Determining the Orientation of a Metal Crystal and a Proposed Tentative Method for Preparing Quantitative Pole Figures of Metals have been prepared and approved by this subcommittee. These were approved by a unanimous vote at the June, 1949, meeting of Committee E-4.

At the June, 1949, meeting of Subcommittee VI it was voted to initiate work on the preparation of standard methods involving the use of microradiography.

Subcommittee VII on Methods of Thermal Analysis (L. H. Carr, chairman) resumed an active status and held a meeting in Chicago, Ill. While recognizing the many deficiencies in the Standard Recommended Practice E 14 for Thermal Analysis of Steel, the subcommittee recommends its continuance for the present. At the same time, a task force was appointed to make a thorough revision of this standard which would include more specific and instructive information and incorporate the best modern methods for thermal analysis. This assignment is to be completed within a year.

The subcommittee had been active previous to the war in establishing a recommended practice in the field of dilatometric analysis. A Proposed Recommended Practice for Dilatometric Analysis of Metallic Materials has been prepared and approved by subcommittee letter ballot during the past year. It was approved by unanimous vote at the June meeting of Committee E-4.

In addition to this project, the subcommittee is also considering other methods of thermal analysis such as resistivity, magnetic susceptibility, etc., and expects to establish recommended practices in these fields.

Subcommittee VIII on Grain Size (M. A. Grossman, chairman).—Section A on Austenite Grain Size (M. A. Grossman, chairman) has had no comments on the Standard Classification of Austenitic Grain Size in Steels (E 19 – 46) and thus has no recommendations.

Section B on Ferrite Grain Size (R. E. Penrod, chairman) has been very active during the past 18 months in preparing a ferrite grain size standard which is being recommended for publication as tentative, as referred to earlier in this report.

Section C on Non-Ferrous Grain Size (C. H. Samans, chairman) has put forth a tremendous amount of effort in reconciling the various and sundry grain count attempts in several branches of non-ferrous metallurgy into a single pattern. They have met with hearty cooperation in such fields as aluminum, magnesium, nickel, etc., and have arrived at a solution which will permit a generally uniform method which directly correlates with other standards.

Proposed Tentative Methods for Estimating the Average Grain Size of Wrought Copper and Copper-Base Alloys has been approved by subcommittee letter ballot and was given a unanimous vote of approval at the June meeting of Committee E-4.

Having inherited the "brass" grain size standard which was deleted from Tentative Method E 2 – 44 T, this Section has corrected several deficiencies in the comparison chart such as inadequacy of range, deficiency in steps in the series, uniformity of structure, etc. In addition, it now becomes possible to use this comparison at 75×, or, preferably, at the presently accepted standard of 100× or multiples thereof which fit into other established grain size comparison charts.

The work involved in establishing a logical system of grain size determinations applicable to non-ferrous metals has been a considerable task. It is a credit to the Section that it has arrived at a system which has all the breadth of application necessary, and which also finds direct correlation with other recognized methods. This bids well to arrive eventually at the only logical conclusion to the end that an acre is an acre, whether of woodland or of pasture, and is measured by the same yardstick.

Subcommittee IX on Inclusions (Samuel Epstein, chairman) has reviewed the Tentative Recommended Practice E 45 for Determining the Inclusion Content of Steel and recommends its continuation as tentative without revision.

Subcommittee X on Decarburization, (J. J. B. Rutherford, chairman) is considering several of the suggested methods for the determination of decarburization. In addition, liaison is being maintained with the Society of Automotive Engineers and other groups interested in this same effort.

This report has been submitted to letter ballot of the committee, which consists of 86 members; 67 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

L. L. WYMAN,
Chairman.

MARY NORTON,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee E-4 presented to the Society through the Administrative Committee on Standards the following recommendations:

New Tentative Method for:

Estimating the Average Grain Size of Wrought Copper and Copper-Base Alloys (E 79 - 49 T),
Preparing Quantitative Pole Figures of Metals (E 81 - 49 T), and
Determining the Orientation of a Metal Crystal (E 82 - 49 T).

New Tentative Recommended Practice for:

Dilatometric Analysis of Metallic Materials (E 80 - 49 T).

Revision of Tentative Recommended Practice for:

Identification of Crystalline Materials by the Hanawalt X-Ray Diffraction Method (E 43 - 46 T).

These recommendations were accepted by the Standards Committee on December 21, 1949, and the new and revised tentatives appear in the 1949 Book of A.S.T.M. Standards, Part 2.

REPORT OF COMMITTEE E-6
ON
METHODS OF TESTING BUILDING CONSTRUCTIONS*

Committee E-6 on Methods of Testing Building Constructions held one meeting during the year, in Chicago, Ill., on March 2, 1949, preceded by meetings of the Advisory and four other subcommittees.

Since the last report, 11 members have been elected and there have been 2 removals. The committee records with sorrow the death of A. J. Boase, one of the original members of the committee. At the present time the committee consists of 57 members, of whom 50 are voting members. The members are not classified.

The committee has no recommendations concerning standards and tentatives to present at this time. The Tentative Methods of Conducting Strength Tests of Panels for Building Construction (E 72 - 47 T) which has stood for two years without revision is now under study in Subcommittee I for recommendation regarding possible revision.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1948 Annual Meeting, Committee E-6 submitted to the Society through the Administrative Committee on Standards, the proposed Tentative Methods of Testing Truss Assemblies. The new tentative was accepted by the Standards Committee on September 29, 1948, and appears in the 1948 Supplement to the Book of A.S.T.M. Standards, Part II, under the designation E 73 - 48 T.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Panels for Light-Building Construction (H. L. Whittemore, chairman) is considering comments on Tentative Methods E 72 with a view to possible revision.

Subcommittee II on Connections and Assembled Structures (G. M. Rapp, chairman) held a meeting in Chicago on March 1, 1949, to discuss its program.

Subcommittee III on Large Structural Units (F. E. Richart, chairman) developed the Tentative Methods of Testing Truss Assemblies (E 73 - 48 T). The subcommittee has been considering the question of type and scope of testing procedures required for tests of large structural members or assemblies and will proceed when an objective is clearly defined.

Subcommittee IV on General Structural Elements (K. F. Wendt, chairman) held a meeting in Chicago on March 1, 1949. The subcommittee has continued its consideration of the proposed Tentative Methods of Tests for Strength and Stiffness of Prefabricated Floor and Roof Constructions for Buildings. The proposed methods have undergone several revisions, and the subcommittee hopes to have a draft ready for action during the year.

Subcommittee VI on Insulation (F. G. Hechler, chairman) held a meeting in Chicago on March 1, 1949. The subcommittee is giving attention to methods for determining heat and water vapor transfer through materials and constructions. Methods for determining both properties have long been under consideration by other A.S.T.M. committees. Acceptable tentative laboratory methods for determining heat transmission have been developed by Committee C-16 on Thermal Insulating Materials. The suitability of a small inexpensive heat-flow meter, now commerically available, is being investigated for use in making field checks of heat transmission of constructions. Several committees are dealing with vapor barriers and water vapor transfer, but no generally acceptable method of test has yet been developed. The subcommittee is keeping in close touch with this work and giving its support to a unification of the basic procedures and the eventual development of a test method suitable for constructions as well as for materials.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27-July 1, 1949.

Subcommittee VII on Sound Transmission (R. K. Cook, chairman) has completed preparation of the first draft of the Test Method for Laboratory Measurements of Airborne-Sound Transmission Loss of Building Floors and Walls. This has been circulated to 14 laboratories and individuals, in addition to members of the subcommittee. Numerous comments and suggestions on the test method have been received and as many of these as possible incorporated into a new draft. This is now before the subcommittee for recommendation as to its approval as tentative.

Subcommittee VIII on Fire Resistance (Harold Perrine, chairman) has been largely engaged in a review of the work of Committee E-5 on Fire Tests of Materials and Construction, to determine whether the program of that committee is adequate to meet the needs of Committee E-6. A subgroup has been established to study the feasibility and need of developing a small scale fire test of wall panels. This would permit a manufacturer to do exploratory work with small-size units, thereby obtaining a wide range of test data before making the official full-size test. A subgroup will also be appointed to define the significance of fire tests and outline the objective of such tests in relation to occupancy requirements.

This report has been submitted to letter ballot of the committee, which consists of 50 members; 36 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

J. A. LISKA,
Chairman.

J. H. COURTNEY,
Secretary.

REPORT OF COMMITTEE E-7
ON
NON-DESTRUCTIVE TESTING*

Committee E-7 on Non-Destructive Testing met at Detroit, Mich. on June 21, 1948, in conjunction with the Annual Meeting of the Society. There have been Executive Council meetings on October 27, 1948, and March 25, 1949.

In conjunction with the expansion of scope of the committee to include non-destructive testing for discontinuities or structural irregularities, rather than radiographic testing alone, the membership has increased steadily throughout the year to 93, including representatives of 8 other technical committees interested in non-destructive testing as applied in their fields of jurisdiction. The members are no longer classified.

Revision of Tentative

The committee recommends that the Tentative Definitions of Industrial Radiographic Terminology for Use in Radiographic Inspection of Castings and Weldments (E 52 – 45 T) be revised as appended hereto.[1] This revision is designed to accomplish two objectives: (*1*) The reorganization of the terms into six groups rather than seven, distributing the terms formerly grouped under the designation "Dispersed Defects" between the groups designated "Gas" and "Shrinkage," as being more indicative of the cause of the indications than the previous designation, and (*2*) the expansion of the section on welding discontinuities to include additional material not included in the original definitions. Opportunity was taken also to make minor editorial changes, primarily for purposes of clarification.

Tentative Continued Without Revision

A special subcommittee, (N. A. Kahn, chairman, Alexander Gobus and O. R. Carpenter), has considered the possibility of revision or adoption as standard of the Tentative Industrial Radiographic Standards for Steel Castings (E 71 – 47 T). In accordance with the subcommittee recommendation to the Executive Council, it is recommended that this tentative be continued in its present form.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

General Activities of the Committee

Discussion on Ultrasonic Testing.—This discussion, held in conjunction with the 1948 Annual Meeting at Detroit, has been reproduced and circulated to the committee. Copies are available for those interested. The two papers delivered at this discussion will be published in a forthcoming book.

Reorganization.—A permanent subcommittee organization to cover the expanded scope of the committee has not yet crystallized, but is being studied by the Executive Council.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] These revised definitions were accepted by the Society and appear in the 1949 Book of A.S.T.M. Standards, Parts 1 and 2.

[2] The letter ballot vote on these recommendations was favorable, the results of the vote are on record at A.S.T.M. Headquarters.

1949 Annual Meeting.—In addition to the usual Executive Council and committee meetings, the committee is sponsoring two technical meetings to be held in conjunction with the Annual Meeting of the Society one on Ultrasonic Testing and the other on Radiography. It is hoped that the material presented at both sessions can be published in book form.

Steel Weld Standards.—A special subcommittee, under the chairmanship of A. Gobus, is exploring the possibility of producing a set of reference X-ray negatives, similar to those in Tentative Radiographic Standards E 71 for Steel Castings covering defects in steel welds, and a set of ultrasonic reflectograms of the same defects.

Radiographic Procedure.—A special subcommittee, under H. E. Seemann, is studying the preparation of a standard radiographic procedure to replace the obsolete Tentative Methods of Radiographic Testing of Metal Castings (E 15 – 39 T) which was withdrawn in 1947.

This report has been submitted to letter ballot of the committee, which consists of 93 members; 59 members returned their ballots, of whom 56 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

J. H. BLY,
Chairman.

D. T. O'CONNOR,
Secretary.

REPORT OF COMMITTEE E-9

ON

FATIGUE*

The major project of Committee E-9 on Fatigue for some time has been the preparation of a "Manual on Fatigue Testing." This project was initiated at a meeting of the committee held during the Annual Meeting of the Society in Buffalo, N. Y., June, 1946, with the assignment of responsibility for various sections to individual committee members. Drafts of the several sections have been discussed at subsequent meetings of the committee at two Annual and three Spring Meetings of the Society, with appropriate revisions resulting. The Manual manuscript, which represents a reasonable consensus of committee opinion and experience, is now completed and needs only minor editorial changes. The publication should be available in the fall of 1949.

During the past year liason has been established between British work in the fatigue field and the work of Committee E-9. Dr. Herbert J. Gough, Chairman of the Properties and Mechanics of Materials Committee of the Mechanical Engineering Research Board of the Department of Scientific and Industrial Research of Great Britain is serving on Committee E-9 as a Corresponding Member. Some exchange of information has taken place; it is expected that this activity will be of considerable benefit to both participants.

Mr. Wm. C. Stewart has been appointed the Committee E-9 representative on the Committee on Corrosion Fatigue of the National Association of Corrosion Engineers.

A Papers Review Committee has been appointed consisting of the following members: J. A. Bennett, C. J. Code, F. M. Howell, J. N. Kenyon, D. G. Richards, W. C. Stewart, and H. H. Zurburg. To date seven potential A.S.T.M. papers have been reviewed by this committee. These will form the basis of a Session on Fatigue at the 1949 Annual Meeting of the Society. A similar Session on Fatigue is scheduled at the Pacific Area National Meeting to be held in San Francisco, Calif., in October, 1949.

In the past the following surveys have been undertaken: (1) Listing of current projects dealing with fatigue of engineering materials; and (2) listing of subjects in the fatigue field where information is needed. These surveys have not been kept up to date due to the large amount of time required for the preparation of the Manual on Fatigue Testing, but it is planned to review the surveys during the coming year.

This report has been submitted to letter ballot of the main committee which consists of 34 members; 19 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

R. E. PETERSON,
Chairman.

O. J. HORGER,
Secretary.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27-July 1, 1949.

APPENDIX

REPORT OF SUBCOMMITTEE ON RESEARCH[1]

This report comprises a number of short paragraphs on several significant features of present-day fatigue testing. There is no pretense of an exhaustive study of the field nor anything approaching a complete list of references.

In the early days of the study of the fatigue of metals, say about up to the turn of the century, the mechanical strength of metals under repeated stress was about the only phase of the problem studied, and a "true" elastic limit was supposed to be the limiting strength of any metal. The metal was supposed to "crystallize" under stresses above that strength. However, in the mid-nineties the work of Ewing, Rosenhain, and Humfrey **(1)**[2] showed that the formation of slip lines and of shear-like sliding were of prime importance as a phenomenon preceding, but not always followed by, the development of spreading cracks to fracture. Since about 1925 studies of the space lattice structure within crystalline grains, and the behavior of metal at the atomic level were recognized as important factors in the problem, together with some chemical factors.

Today the yearly publication of data of hundreds of fatigue tests and of a large number of metallurgical, atomic, and mechanical-strength tests have so increased the volume of available literature that no one man can be familiar with the whole field of fatigue of metals. However, it is hoped that the discussion of the tests and the references given in this report will be of value.

The recent study of fatigue problems has emphasized the fact that our conventional methods of computing stress, strains, and energies in stressed material are based on the assumption of homogeneity in the metal. The microscopes of Ewing, Rosenhain, and Humfrey **(1)** and other metallurgists long ago showed us that this is not the case, and we have found that Hooke's law is approximate and has definite limits of usefulness in stress analysis. We are fast coming to regard the results of conventional stress analysis as statistical in nature, based on probability rather than on rigidly true facts **(2)**. This does not mean that we have abandoned the conventional formulas for computing stress, strain, and strain energy, but that we regard them as having, on the whole, proved reliable for general use as a basis for design, especially as they nearly always give results on the safe side, as shown by tests. The good old engineering principle of using the best tools available, even if they are imperfect, extends to the methods of computation of the probable strength of materials.

The Crystalline Mechanism of Fatigue Fracture:

Assuming that stress may be considered as the dominant dangerous agent, the present-day view of the progress of repeated stress damage and final fracture of a specimen or of a machine part follows, in general, the picture given by Ewing, Rosenhain, and Humfrey **(1)**. The first change noted in the common stress-carrying metals is a change on a microscopic scale. There appear series of lines (called "slip lines") across crystalline grains of the metal. These seem to extend in various random directions, but studies of the atomic structure of such grains show that slip lines follow along one or more of a limited number of crystallographic planes, and that the particular plane in a crystalline grain on which the slip lines appear is that atomic plane along which the shearing component of the applied stress is a maximum for that grain.

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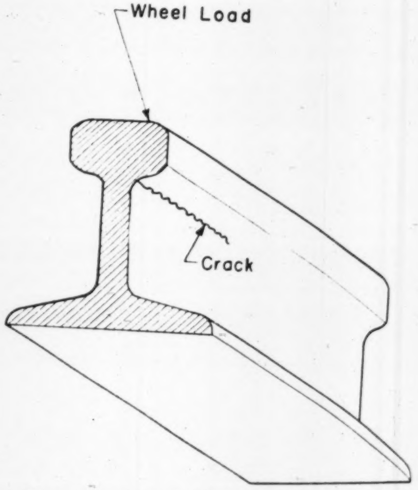
[1] Presented by H. F. Moore, Chairman of E-9 Subcommittee on Research.

[2] The boldface numbers in parentheses refer to the list of references appended to this report, see p. 531.

As cycles of stress continue to be applied, the slip lines widen, and, if the stress continues sufficiently great at each cycle, a very definite crack opens. Tensile and compressive stresses ("micro" stresses) with components at right angles to the slip lines cause fragmentation of very small particles and the crack tends to continue to spread, finally causing fracture. If the crack in its spread encounters a highly resistant arrangement of crystalline grains, with such orientation of slip planes as make the further spread of the crack difficult, the crack *may* be stopped before fracture. A very few such cases of stopping a spreading crack have been observed, but the probability of stopping a fatigue crack well underway was seen to be negligible, unless some other crack in another location of the specimen or part starts and grows faster than the first crack. Such a phenomenon has been observed, but is not common.

In a good many observed cases, fatigue cracks take their initial direction along a slip plane, but the stresses at the end of the crack are greatly intensified, and the crack as it spreads tends to change its course to a direction at right angles to the principal tensile stress in the immediate vicinity of the point of the initiation of the crack, and the final direction is generally approximately at right angles to the principal tensile stress (Note).

NOTE.—Under cycles of compressive force the course of the crack is less well known. Higher compressive force is required to develop a crack than is required under corresponding cycles of tensile force. Under cycles of non-reversed stress, either tensile or compressive, a crack nearly always develops under a stress above the yield strength of the metal, and under succeeding cycles of imperfectly elastic action, localized tensile stress may be developed in a region of nominally compressive stress. If the specimen is small or thin, buckling may take place under compression, with a resulting tensile stress on the convex side. During cycles of compression there may occur shearing slip along slip planes within a crystalline grain, fragmentation of particles along the slip planes as the compressive load is applied, and setting up of tensile stress and opening of cracks upon release of the compressive load. The relative significance of these three potentially damaging actions is still a matter of lively debate.

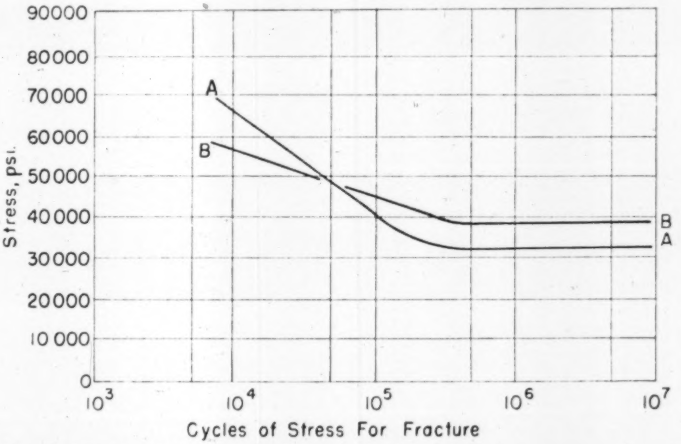


The crack was caused by eccentric wheel loads, probably in curved track. The crack is in a region of nominal compressive stress.

Fig. 1.—Crack at Junction of Head of a Railroad Rail.

It is to be remembered that when considering the entire stress pattern of the specimen or the machine part, the three principal stresses and the resulting diagonal shearing stresses must be considered. Except under triaxial stress with all three principal stresses equal in magnitude and all either tension or compression, there is always shearing stress present. The question of the importance of the shearing stress is still a subject of debate.

The problem of the starting and spread of a fatigue crack in a region in which the maximum principal stress would be compressive, *if the material remained elastic throughout*, has been raised by failures in service of railroad rails (3) in which a longitudinal crack develops at the junction of head and web of rail under an eccentric wheel load which tends to produce compression in this region (Fig. 1). This condition is most frequently found on curved railroad track.



Steel A shows the higher strength up to about 50,000 cycles of stress.

Steel B shows the higher strength above 50,000 cycles of stress. Short-time repeated-stress tests of two metals are not reliable as a measure of their respective strengths under long-time service.

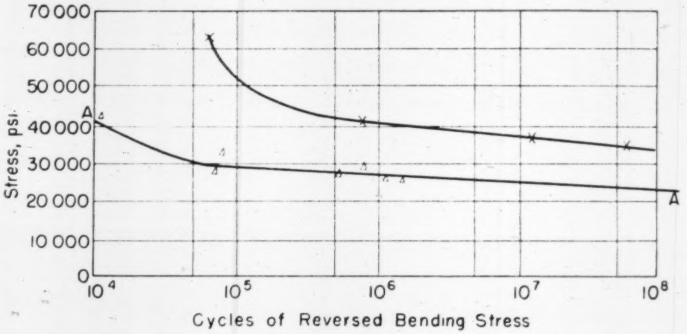
Fig. 2.—*S-N* Diagrams for Two Different Steels.

Can Fatigue Strength of Full-size Structural or Machine Parts be Predicted from Test Results of Small Specimens?

This question is still under lively discussion (4). It is obvious that the ideal method of fatigue tests would be to make tests on full-size parts, with their natural surface conditions. However, especially for large parts or for assembled machines, this would be extremely expensive and, what is worse, time-consuming. If only a few parts are tested the *S-N* diagram is distinctly less reliable as a guide for design.

Another limitation of full-size fatigue tests is met in such tests as proving ground tests, in which an assembled machine is subjected to a period of hard service, and, if it stands this period of abnormally hard service satisfactorily, it is assumed that it will be satisfactory under ordinary service *for a long time*, involving very many cycles of relatively light stress. Now it has been found from tests of specimens that it is not at all certain that specimens which resist successfully a few cycles of high stress will show satisfactory endurance under a very large number of cycles of low stress. Sometimes the *S-N* diagrams of two metals cross, as is shown in Fig. 2 in which metal *A* shows the greater endurance under cycles of high stress and metal *B* under cycles of low stress.

One limitation of the usefulness of fatigue tests with small prepared specimens is the difference in surface conditions between such specimens and full-size parts. In some cases the surface conditions can be made very nearly the same, and this should be done if the test results are to be used as a basis for design. A second limitation is the "size effect" which is not fully understood, but, in some metals causes large specimens to fail under lower calculated stress ranges than those which small specimens will withstand. A third limitation of laboratory tests is the difficulty of reproducing in small specimens the same load pattern as that found in the full-size part under service conditions. Then there is the difficulty of predicting the shape of the *S-N* diagram for stresses *above* the endurance limit for indefinitely long endurance. This part of the diagram may be different for the full-size part from what it is in the small specimen. In many structural parts, such as bridge members and railroad rails, and in some machines which are only rarely subjected to their maximum load this upper part of the *S-N* diagram is of more importance than the endurance limit for indefinite "life."



These diagrams are for two precision cast specimens of high-temperature-resistant alloys and were tested at 1500 F. Note the downward slope of the diagrams at 100,000,000 cycles of stress.

Fig. 3.—Two Typical *S-N* Diagrams from the Test Results of Toolin and Mochel.

Brittleness and Fatigue of Metals:

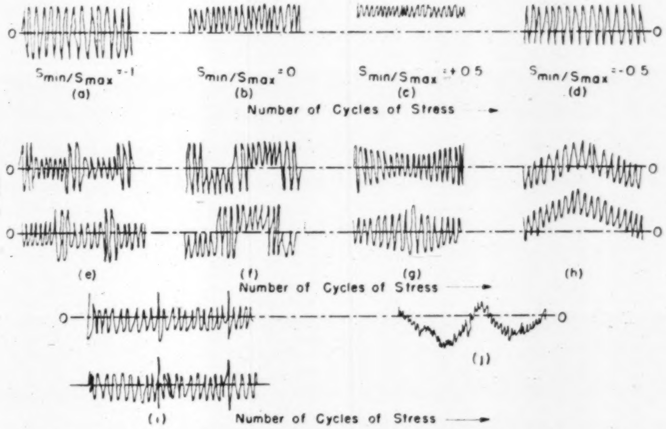
It has been found that when subjected to cycles of repeated stress of constant *range of stress*, metal which shows little elongation at fracture in a tension test may show high resistance and good length of "life." Cast iron has been used for crankshafts, and high-carbon steel hardened shows high values of endurance limit for very large numbers of cycles of stress, if no occasional cycles of abnormally high stress are allowed to occur.

However, the use of brittle metals is not advisable if occasional cycles of high stress do occur, as is the case in railroad rails. Rail steel is fairly high-carbon steel, but it is used after slow cooling, and then has from 7 to 9 per cent elongation in the tension test.

It has been found (5) that with deep carburization and hardening of steel, the fatigue test results on specimens showed very high values of stress, but in a tension test the specimens showed less than 1 per cent elongation. Brittleness is to be avoided in metal which is to be subjected to cycles of repeated stress unless it is reasonably certain that the part will *not* be subjected to occasional cycles of very high stress. This is the case with coil springs with positive stops to limit deflection, and steel for such springs does not require a large elongation in the tension test.

Fatigue Strength at Elevated Temperature:

The development of the gas turbine has added emphasis to the demand for metals which under repeated stress will withstand temperatures up to 1500 F., or even higher. A considerable amount of fatigue testing has been done at temperatures as high as 1500 F. (6).



Maximum stress (S_{max}) is shown as the same for each spectrum.

Fig. 4.—Various Spectrums of Cyclic Stress.

Some years ago at the University of Illinois, fatigue tests under cycles of reversed stress at a temperature of 1200 F. were made on specimens of S.A.E. 1020 plain carbon steel. Tests were made at 300 cycles per minute and at 2500 cycles per minute. The ordinary *S-N* diagram showed that under 300 cycles per minute the number of cycles of stress necessary for fracture at a given stress was much smaller than the number of cycles necessary at 2500 cycles per minute. However, if the test diagram was plotted with stress at ordinates and *duration* of test in hours as abscissas the same curve fitted both the test results for the tests at 300 cycles per minute and those for 2500 cycles per minute. This *coincidence* in the test results for carbon steel at 1200 F. are not believed to be of much significance. Some tests of fatigue of lead strip under reversed bending which have been made at the University of Illinois indicate that, for this very soft metal, as the frequency of cycles of stress increases the number of cycles necessary for fracture increases, but the *elapsed time* for completing a test decreases as the frequency of cycles increases.

It seems probable that, at temperatures which would cause creep in the metal, creep is present as a factor during a repeated-stress test. The creep occurs only during a portion of the time occupied by a cycle of stress. The number of cycles of stress is a most significant factor in determining fatigue life, while under creep *time* is the corresponding factor. Under a combination of repeated cycles of stress and creep a complex rate of damage is set up, which demands attention. Under high temperatures the frequency of cycles of stress becomes a major factor, while below creep temperatures it is usually a minor factor. Under ordinary room temperatures the common ferrous stress-carrying metals do not show much difference in the endurance limit for frequencies of stress cycle varying from a few hundred up to 5000 per minute.

The influence of creep during fatigue tests of metals at high temperature are also shown in the very extensive tests made by Toolin and Mochel (6). Their fatigue tests were run at a speed of 7200 cycles per minute and at temperatures of 1200 and 1500 F. (Fig. 3). Now in fatigue tests of ferrous metals the *S-N* diagram usually "flattens out" to a horizontal line as the number of cycles of stress becomes very large, while in a creep-test-to-fracture the log stress-log time diagram is usually a straight line sloping downward. Nearly all the Toolin-Mochel *S-N* diagrams show a flattening out, but a flattening out to a *downward inclined* line.

Fatigue Under a "Spectrum" of Repeated Stress Patterns:

In laboratory fatigue tests, specimens are usually subjected to cycles of stress with a constant amplitude and a constant ratio of minimum to maximum stress. This is rarely the case in machine parts. Figures 4(*a*) to (*d*), inclusive, illustrates common laboratory "spectrums" of stress, and Figs. 4(*e*) to (*i*), inclusive, illustrates a number of spectrums in which either the amplitude or the ratio of minimum to maximum stress varies. Obviously the number of possible "spectrums" of stress is indefinitely large, and all research which seems possible is the investigation of a limited number of such spectrums, choosing spectrums which seem to most nearly imitate spectrums which may be applied to machine parts in service. Some such tests have been made and reported (7) and interest in this matter is quite keen among students of fatigue of metals.

Figure 4(*j*) represents, not so much a "spectrum" as a stress record of a type sometimes found in airplane wings in flight. No well-defined cycle of repeated stress can be readily selected as representative of such a complex stress history.

Residual Stresses and Their Importance:

In many machine and structural parts there are present residual (locked-in) stresses in various locations. These residual stresses may have been caused by ordinary or extraordinary loading, heat treatment, welding, temperature changes, rapid cooling, hot rolling or forging, cold rolling or drawing, cold hammering or shot peening, or machining and polishing. These stresses are in some locations tensile stresses and in other locations compressive, and there are nearly always shearing residual stresses present. Throughout the piece the tensile forces must balance the compressive forces. This balance depends on the relative intensity of tensile and compressive stresses and on the area over which each acts.

Compressive residual stresses usually add to the fatigue strength, since they tend to offset destructive applied tensile stress and to reduce slipping action under applied shearing stress. Tensile residual stresses tend to weaken the metal at the location where they exist.

Residual stresses may be partially or wholly removed by heating slightly below the critical temperature of a metal, or by applications of repeated stress somewhat above half the stress at the yield strength of the metal (8).

The problem of setting up beneficial residual stresses and of causing the accompanying injurious residual stresses to locate in localities where the applied stresses are low is of considerable interest today. The earlier practice was to treat all residual stresses as undesirable and to get rid of them as thoroughly as possible. However, today, faced with the growing necessity of taking advantage of all means of strengthening machine and structural parts, the utilizing of beneficial residual stresses is of considerable importance, as is the locating of injurious residual stresses in those locations where they will do the least harm.

Effect of Surface Condition on Fatigue Strength:

It is natural to think of the surface of a machine part as containing the area of greatest weakness, since our methods of stress analysis indicate that the principal maximum stress is usually at the surface. However, the surface of a part always has had some treatment different from that received by the metal below it. The cooling rate of the surface of a casting is different from that of the metal below it. If the surface is finished by machining, grinding, or polishing there are contradictory effects on its strength. Rough machining tends to tear up the surface and leave shallow but sharp scratches which tend to act as stress raisers. Fine machining does less damage by making scratches, and usually does some slight beneficial cold working. Grinding leaves a relatively smooth surface, and may do a little cold working. Polishing smooths out scratches and does quite a bit of shallow cold working, so that by quite common methods of surface finishing the surface of a machine part may be either strengthened or weakened in comparison with the metal below it, depending on the surface finishing process used.

Carburizing, nitriding, surface hardening, cold rolling or drawing, cold hammering, and shot peening are processes which set up a surface *zone* of strengthened zone of strengthened metal. They may also set up injurious stresses within the metal, and the techniques of surface treatment are many and of various effectiveness. The critical layer of metal may be moved from the surface to the junction of the strengthened layer with the base metal. The problems of surface treatment are many and are of marked importance today.

Fatigue Testing Machines:

The use of large capacity machines for making fatigue tests is rather steadily spreading. The simplest type of large fatigue testing machine is the single lever type as used by Templin at the Aluminum Research Laboratories and by W. M. Wilson at the University of Illinois. Machines of this type have been built with a capacity of 100,000 lb. pull or push, and a number of machines of ±50,000 lb. capacity are in service.

The Amsler pulsator type of machine is in use in at least one laboratory in this country, with a capacity of ±200,000 lb. Both of these types of machines run at relatively slow speeds, about 175 cycles per minute for the single-lever machines, and about 200 to 300 cycles per minute for the Amsler pulsator.

Several large rotating-beam machines are used by Horger at the Timken laboratories. Some of these can test shafts 11 in. in diameter. They run at fairly high speed and the specimen is artificially cooled. They are limited to tests under cycles of reversed bending stress.

Large fatigue testing machines which operate by resonance of push-pull forces set up by small rotating eccentric weights or by electromagnetic vibrators can attain high frequency of cycles of stress with accompanying reduction of the time required for a test, and they require low-powered motors to drive them, but they require an elaborate set of controls to maintain resonance as the elastic action changes or a fatigue crack starts to spread. These machines are very expensive. Several large machines of this type are in use in this country.

Another limitation of the use of tests of large specimens is the expense of the specimens and the increased cost of making tests of large specimens. With small specimens one man can run tests on several machines, but with large specimens several men are required to set up the specimen in the machine and to remove broken specimens.

Large machines in use for special tests of special parts include a large number of machines for testing springs. These machines range in capacity from a few pounds for testing small springs to several tons for testing large flat and coil springs. "Rolling-load Machines" for fatigue tests on full-section specimens of railroad rails are in use at the University of Illinois and at several railroad laboratories and at least one welding laboratory.

Small fatigue testing machines of the vibratory type are in wide use. The rotating-beam machines are easy to handle and subject specimens to a constant bending moment, but they cannot readily be used to test specimens under any other cycle than that of reversed bending. Vibratory machines can be used for non-reversed cycles of stress. With a simple attachment, repeated torsion tests can be made on a vibratory fatigue machine. Some vibratory machines use eccentric rotating weights to set up the bending moment; these machines run at very nearly a constant range of bending. Other types depend on the deflection of the specimen itself or of a spring attached to the specimen for measurement of moment. The deflection indicator has to be watched at intervals during a test to make sure that the moment does not vary seriously as the test proceeds.

Fatigue machines for tests under high temperature and machines for tests under low temperature are found in a number of laboratories. Special torsion machines, some of them of large size, are in quite common use, and small tension-compression (push-pull) machines for testing small specimens in repeated axial stress are quite common, as are special rotating-beam testing machines for wire in which the wire is rotated while buckled into an elastic curve and thus subjected to cycles of reversed bending stress.

Short-Time Tests for Fatigue Strength:

A fatigue test which requires but a short time to make and which will predict with a good degree of accuracy limiting stresses for long-time service is still desirable, and unattained. In its beginning stages a spreading fatigue crack does not seem to effect elastic strength, temperature, elastic resistance, or tensile strength to a sufficient degree to be useful as a prediction of long-time fatigue strength.

The spreading crack can be first detected under a magnifying glass only when fracture is imminent, and under a high-powered microscope it is difficult to detect the difference between grain boundaries and fine cracks in their early stages. Slip lines can be detected fairly early in the course of a fatigue test, but while cracks usually begin in regions of shearing slip, not all regions of shearing slip develop cracks.

Possibilities have been suggested of using some effect on the damping of fatigue specimens when vibrated after a relatively short period of cycles of repeated stress. Is the rate of dying out of free vibrations in a specimen altered during the early stages of a fatigue test, and is that alteration reliable and useful as a basis of estimation of the endurance limit? Along the same line we may ask would the number of cycles for fracture of a specimen under a relatively few cycles of a high stress following, say, 100,000 cycles of a low stress, be any criterion for the endurance limit?

Fatigue fracture is a highly localized phenomenon; the results of fatigue tests have "statistical" rather than definite values; at elevated temperatures repeated stress is accompanied by "creep" of the metal. Tests of full size machine parts are desirable, but the cost and time required for testing a sufficient number of large specimens to get thoroughly reliable results limits the scope of full-time testing. Fatigue tests of prepared small specimens give results which, before using them as a basis for design, should be modified by considering surface finish, size and shape of specimen, range of stress during a cycle, residual stresses, and the probable load and moment pattern which the piece will have to withstand in service and possibly other factors.

Respectfully submitted on behalf of the subcommittee,

H. F. MOORE,
Chairman.

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REPORT OF COMMITTEE E-11
ON
QUALITY CONTROL OF MATERIALS*

Committee E-11 on Quality Control of Materials, which was organized in June 1946, to promote the knowledge of statistical quality control methods and their application to specifications and methods of test, has at the request of other technical committees of the Society, given assistance and guidance in standardization problems of a statistical nature. The activities of the committee have been aimed at preparing a series of sections of an A.S.T.M. Manual on Quality Control of Materials presenting discussions on statistical quality control methods of direct application to A.S.T.M. standardization activities.

Copies of the Symposium on Usefulness and Limitations of Samples[1] sponsored by Committee E-11 last year, have been sent to the officers of other A.S.T.M. technical committees. Considerable interest in this symposium has been expressed by some of the committees.

The present officers of the committee have been re-elected for the ensuing term of two years. Messrs. W. E. Deming, J. H. Curtiss, and Grant Wernimont were elected to the Advisory Committee.

Revisions of the Tentative Recommended Practices for Designating Significant Places in Specified Limiting Values (E 29 – 48 T) have been prepared and are out to letter ballot of the committee. These will be presented to the Administrative Committee on Standards in the near future.[2]

ACTIVITIES OF TASK GROUPS

The work of task groups preparing Sections 1, 2, and 3 of the new A.S.T.M. Manual on Quality Control of Materials is nearing completion. It is expected that publication may be possible during the latter part of this year. This work is a revision and enlargement of the A.S.T.M. Manual on Presentation of Data.

A recommended practice for conducting interlaboratory studies of test methods is in the course of preparation. It is expected that this practice will give specific recommendations for the planning, collection, and interpretation of data collected in interlaboratory trials sponsored by A.S.T.M. committees for standardization.

Other subjects being studied by organized task groups include a survey of sampling plans used in A.S.T.M. standards and tentatives to disclose the variety and types of materials in such manner as to make statistical evaluation of these plans possible. A brief presentation on the distribution of averages of samples of size "*n*" from a known distribution is being prepared.

A paper on "Sampling of Bulk Materials,"[3] by Louis Tanner and W. E. Deming, will be presented on June 29, during the 1949 Annual Meeting of the Society in Atlantic City, N. J.

Task groups have been authorized on the sampling of bulk materials, on the smoothing of empirical data, and to study problems connected with the use of words "precision," "accuracy," and allied terms. These groups are now being organized.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] Issued as a separate publication, December, 1948.

[2] See Editorial Note p. 533.

[3] See p. 1181.

This report has been submitted to letter ballot of the committee, which consists of 20 members; 18 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

H. F. DODGE,
Chairman.

O. P. BECKWITH,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee E-11 presented to the Society through the Administrative Committee on Standards the recommendation that the Tentative Recommended Practices for Designating Significant Places in Specified Limiting Values (E 29 - 48 T) be revised. This recommendation was accepted by the Standards Committee on September 22, 1949, and the revised tentative recommended practices appear in the 1949 Book of A. S.T.M. Standards, Parts 1, 2, 3, 4, 5 and 6.

REPORT OF COMMITTEE E-12
ON
APPEARANCE*

Many technical committees of the Society have an interest in various phases of appearance properties of engineering materials. Recognition of the need for a central coordinating agency to whom all of the other technical committees might turn for expert advice on the subject has led to the authorization of Committee E-12 on Appearance by the Board of Directors.

Committee E-12 held an organization meeting on September 14, 1948, at Society Headquarters, Philadelphia, Pa. An Organization Subcommittee, appointed at this first meeting to develop a program of work, held meetings on September 14, 1948, and January 28, 1949. A second meeting of Committee E-12 was held in Chicago, Ill., on March 3, 1949.

The committee now consists of 49 members. In view of the fact that this committee will be primarily concerned with appearance problems which arise in other technical committees, it is hoped that along with increased activity there will be an increase in representation from these committees.

The following officers have been elected:

Chairman, M. Rea Paul
Vice-Chairman, R. C. Adams
Secretary, Daniel Smith

The following is a statement of scope covering the activities of the committee:

Scope.—To improve and develop methods for describing and evaluating the appearance properties (such as color, gloss, opacity, and texture) of engineering materials by:

1. Formulating terms and definitions generally applicable for describing the appearance of engineering materials.
2. Developing, or coordinating with technical committees the development of, standard methods of measurement of fundamental and general appearance properties.
3. Assisting the technical committees to improve appearance tests by advice and suggestions.
4. Reviewing and recommending approval or revision of all A.S.T.M. standards, existing or proposed, involving appearance factors.
5. Serving, with the approval of the Board of Directors, as liaison agent between the Society and other organizations in matters concerned with factors of appearance.

Three subcommittees are being organized to implement the work of the committee. The scopes of these subcommittees and the chairmen appointed are as follows:

Subcommittee I on Definitions (R. S. Hunter, chairman):

1. Prepare definitions of the terms and nomenclature for appearance factors which are used in Society standards and publications.
2. Coordinate such definitions as necessary with other technical committees and organizations either through the Advisory Subcommittee or by its direction.

Subcommittee II on Review (J. H. Calbeck, chairman):

1. Review new material offered to the Society which deals with appearance factors and recommend (*a*) revision, (*b*) coordination with existing standards, (*c*) additional test work (possibly in

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* Presented at the Fifty-second Annual Meeting of the Society, June 27 – July 1, 1949.

cooperation with Committee E-12), or (*d*) publication as submitted.

2. Review all present standards and tentatives for appearance factors requiring definition, coordination, new test methods, or improvement of present methods.

Subcommittee III on Methods (F. C. Schmutz, chairman):

1. Develop standard methods for measurement of appearance properties of engineering materials including: definition of the principle of measurement, evaluation of existing instruments, or design of new instruments.

2. Cooperate with other technical committees in the development of methods involving appearance properties to improve the present methods, to provide methods for new needs, and to coordinate existing methods which are to any extent duplicates.

3. Conduct or arrange for cooperative tests, if needed, to establish the reliability or applicability of apparatus and methods.

Respectfully submitted on behalf of the committee,

M. REA PAUL,
Chairman.

DANIEL SMITH,
Secretary.

TECHNICAL PAPERS

With Discussions

EDGAR MARBURG LECTURE

The purpose of the Edgar Marburg Lecture is to have described at the Annual Meetings of the American Society for Testing Materials, by leaders in their respective fields, outstanding developments in the promotion of knowledge of engineering materials. Established as a means of emphasizing the importance of promoting knowledge of materials, the Lecture honors and perpetuates the memory of Edgar Marburg, first Secretary of the Society.

RESIDUAL STRESSES IN METALS[1]

Twenty-third Edgar Marburg Lecture

By William Marsh Baldwin, Jr.[2]

It is just 35 years since Prof. E. Heyn, then of the Royal Technical Institute, Charlottenburg, and Director of the Royal Prussian Institute for Testing Materials, Berlin, Lichterfelde delivered the May Lecture before the British Institute of Metals. His lecture **(1)**[3] was the first comprehensive review of the subject of residual stresses in metals. The present lecture will be in the nature of a progress report made one generation after this pioneer work. The audience may judge for itself whether this past generation has contributed a full share to our present understanding of the subject.

Residual stresses refer to a system of stresses that exists in a body free from external force or restraint. If isolated mismatching portions of a body are assembled and forced into a continuous whole, each portion must accomodate itself into a compatible shape through mutual reaction with its partners. This accomodation is accomplished by strain. And this strain induces the stress system we call residual stresses. The relationship between the stresses and strains, incidentally, is elastic, for if at any point the body were plastic it would yield to the extent that the stress-strain relationship at that point would subside into the elastic range.

A crude example of this mechanism by which residual stresses are formed would be the case of an inserted die (Fig. 1). Here, if we regard the duplex assembly as a continuous whole, we can readily appreciate that the oversize insert or nib when pressed into the undersize collar will be accomplished by a mutual adjustment in shape: the nib will shrink and the collar will expand. These strains will develop residual stresses in the assembly. In the tangential direction, for example, the collar, being stretched, will be under tension, and the insert, being compressed, will be under compression.

A similar example is the case of a metal in which a second phase has been precipitated. If the precipitated phase occupies more volume than the parent metal from which it sprung, it, in the manner of the oversize nib of the die, will create (among other stresses) tangential tensile stresses in the enveloping matrix (Fig. 2).

The mismatching of various regions of a metal part responsible for residual stresses can be more subtle, however, than that existing between two *parts* or *phases*. Mismatching can occur within a single homogeneous piece of metal. The case of a cooling hot ingot is an example (Fig. 3). The edges of such a slab presumably cool faster than the center. The thermal contraction associated with this drop in temperature gives rise to a mismatch between the edges and center of the ingot which would result in longitudinal tensile stresses (among other stresses) in the edges and longitudinal compressive stresses in the center (Fig. 3(*b*)). The low yield strength of the hot center, however, cannot withstand the action of the compressive stresses and the center shrinks plastically. When the center of the bar finally cools and contracts, the total contraction will be greater than that suffered by the outer skin, since the center shrunk some by plastic flow in addition to contracting during cooling. The center will then be in tension and the edges will be in compression. These stresses will be maintained because the metal is now cold throughout the ingot and the yield strength is high.

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[1] Read on June 28, 1949, before the Fifty-second Annual Meeting of the Society, Atlantic City, N. J.

[2] Research Professor, Case Institute of Technology, Cleveland, Ohio.

[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 581.

The residual stresses in the above case arose from inhomogeneous plastic deformation of the metal throughout the bar. Such deformation need not necessarily be caused by thermal effects but may arise when simply mechanically induced, by such means as extrusion, bending, and so on.

Timoshenko (2) indicates the general method by which residual stresses may be calculated. In essence the residual stress distribution is given by the difference in stress distributions calculated from the strain distribution in the metal using both the plastic and elastic stress-strain relationship for the metal in question (3).[4] Except in the simplest cases this procedure is beyond our power at the present time. One such simple case (4) is given here as an example, however.

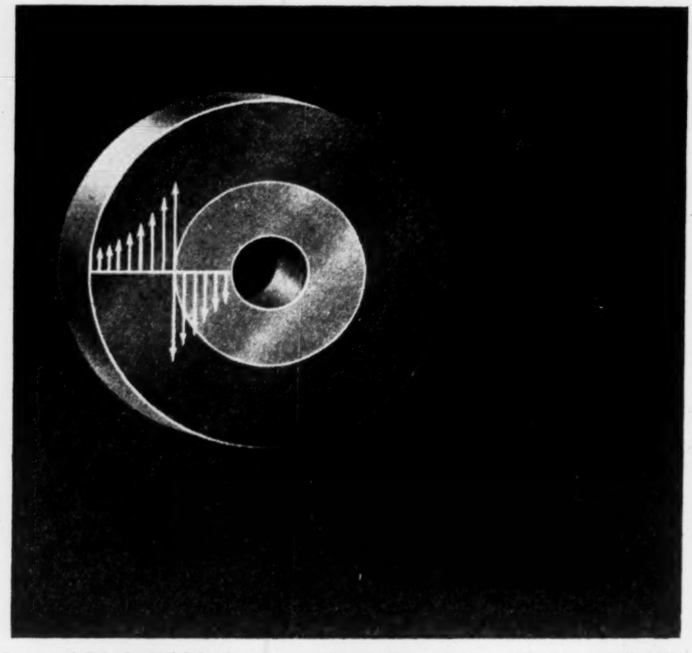

FIG. 1.—An Inserted Die in Which the Outer Ring is Shrunk onto the Inner Nib. The natural mismatch between the two creates tensile hoop stresses in the outer ring and compressive hoop stresses in the inner ring.

1. A prismatic bar (Fig. 4(*a*)) is subjected to a bending moment constant along the length of the bar. In reaction to

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[4] Thus if the strain distribution is known the residual stress pattern is derivable. The converse is not necessarily true.

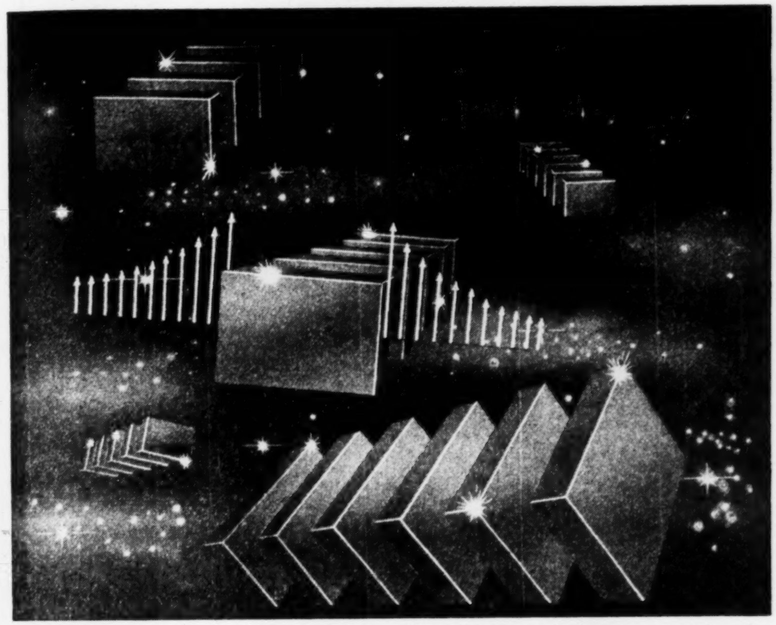
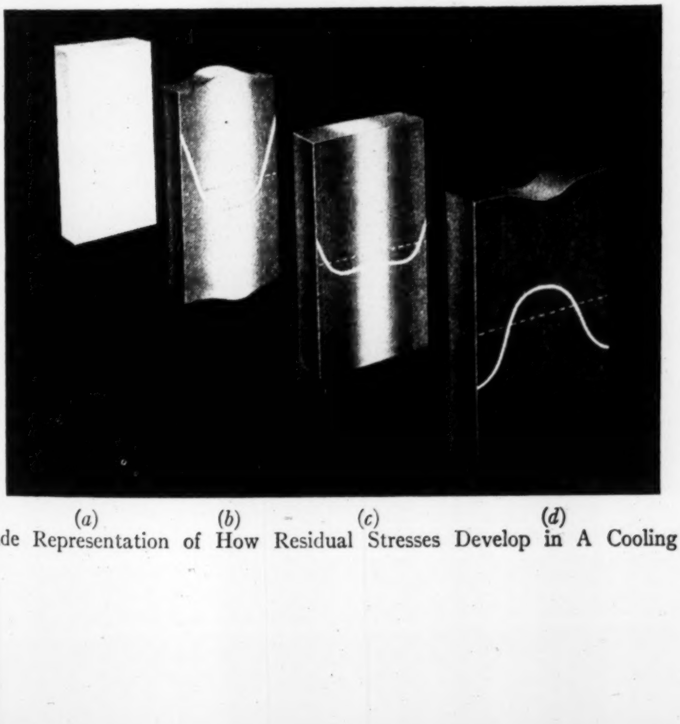


FIG. 2.—An Interior "Microscopic" View of a Metal in Which a Relatively more Voluminous Phase has been Precipitated.

The precipitate is put under compression and the surrounding matrix will suffer—among other stresses—tensile stress running circumferentially around the precipitate.



(a) (b) (c) (d)

FIG. 3.—Crude Representation of How Residual Stresses Develop in A Cooling Hot Ingot.

this moment an internal stress field arises. As you may recall from elementary theory of beams, the internal stress will be tensile at one edge of the bar decreasing linearly in magnitude passing through zero at the neutral axis of the bar and increasing linearly toward a maximum value of compression on the other edge of the bar (Fig. 4(*b*)).

2. Presume now that the prismatic bar, before this bending moment is applied, possesses internal stresses of the distribution shown in Fig. 4(*c*). The application of the same bending moment as above gives rise to the same internal stresses reaction. The superposition of this reaction (Fig. 4(*b*)) on the initial internal stress distribution will result in the saw-toothed stress distribution shown in Fig. 4(*d*).

3. The initial stress pattern in Fig. 4(*c*) is in point of fact the stress distribution that would exist in a prismatic bar subject to a bending moment that rendered the entire bar plastic (assuming the metal evidenced no work hardening). The application of a bending moment equal in magnitude but opposite in direction has left the bar free from all external moments, and the saw-toothed stress distribution in Fig. 4(*c*) is thus the *residual* stress pattern that results upon bending a bar plastically and then withdrawing the moment that effected this action. Experimental studies (**5**, **6**) on the residual stresses in bent bars have corroborated this approach.

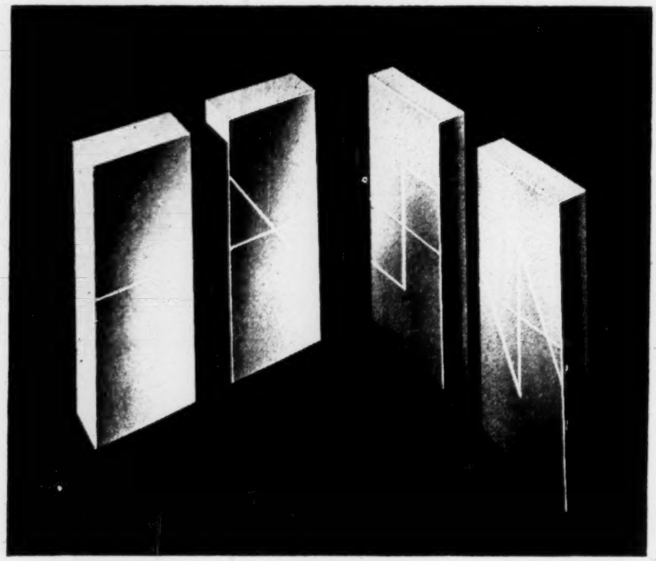

(*a*) (*b*) (*c*) (*d*)

FIG. 4.—Explanation of How Residual Stresses Can Develop as a Result of Cold Work.

MEASUREMENT OF RESIDUAL STRESS

It is well to discuss first of all how residual stresses are measured, for it should be understood in the beginning that the methods of determining residual stresses are in most cases approximations (for reasons that will become apparent) and the nature and magnitude of the inaccuracy introduced by such approximative methods should be borne in mind when discussing the reported residual stress systems, found in metals that are cast, welded, heat treated, worked, etc.

Residual stresses are never measured directly. No practical balance or manometer has ever been invented to do the job required. Residual stresses are measured instead indirectly through the strains that exist in a residually-stressed metal. The general method of revealing and measuring the strains in a residually-stressed body is to reverse the process by which they were created: to isolate regions of the continuous whole and observe the resulting mismatch. A simple illustration of this general technique is the specialized method introduced by Bauer and Heyn (**7**). These gentlemen considered the case of a cylindrical rod containing longitudinal residual stresses tensile in the outer hull of the rod and compressive in the core. Heyn (**1**) struck an analogy for this stress pattern (Fig. 5): the tensile stresses in the outer layers of the rod could be thought of in terms of stretched springs, the compressive stresses in the inner layers of the rod in terms of bunched springs, both sets of springs being fixed to crossheads at either end. The removal of the outer springs would allow the central bunched springs to lengthen, and the amount of the expansion would indicate the force in the outer springs which had restrained them

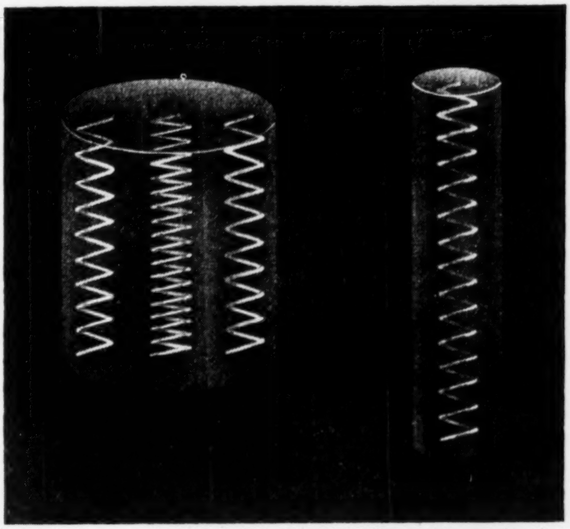
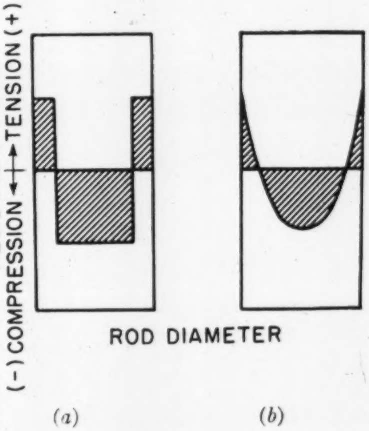


FIG. 5.—Heyn's Spring Analogy of his Residual Stress Determination Method.

A cylinder is presumed to possess longitudinal residual stresses—tensile in its outer layers, compressive in the inner layers. If the outer layers are machined away, the central core, freed of restraint, will lengthen.



(*a*) (*b*)

FIG. 6.—Residual Stresses in a Rod.

A rod having a constant residual stress in an arbitrary case and core is shown in (*a*), while a rod having continuously changing residual stresses from surface to center is shown in (*b*).

Specifically, the expansion, $d\epsilon_1 = \frac{dl_1}{l}$, (where l is the length of the rod and dl_1 is the increase in length) of the central core, by Hooke's law, is proportional to the stress, S_r, relieved during expansion, that is,

$$S_r = Ed\epsilon_1$$

In turn, the product of this stress, S_r, and the area, A_1, of the central core is the force which counterbalanced the force of the removed skin:

$$F_{\text{core}} = A_1 Ed\epsilon_1 = F_{\text{skin}}$$

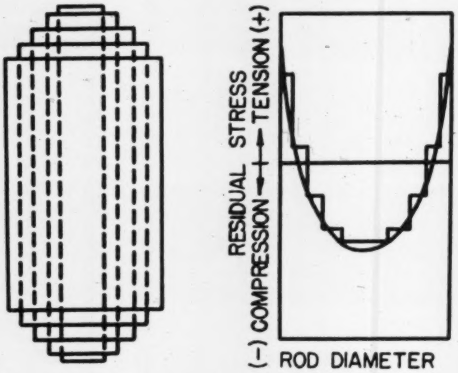


FIG. 7.—Bauer and Heyn's Residual Stress Determination Method When Carried Out in a Succession of Small Steps Gives a Satisfactory Approximation to a Continuously Changing Stress Distribution

The force of the removed skin of course was the product of its area, $dA_1 = A_0 - A_1$ (where A_0 is the area of the original bar), and the average residual stress $\bar{S}_1$ that existed within it,

$$F_{\text{skin}} = \bar{S}_1 dA_1$$

Thus:

$$\bar{S}_1 = \frac{A_1 E\, d\epsilon_1}{dA_1} \quad \dots\dots\dots (1)$$

Now it is intuitively obvious that in the general case there is no arbitrary "case" or "core" of a rod each having a constant residual stress but that stresses will vary in a continuous manner from the skin of the bar to its center (Fig. 6).

Bauer and Heyn's method is still applicable in this instance, however. The residual stresses from surface to center can be approximated by removing a succession of thin layers from the rod. In each instance, the expansion (or contraction) of the remaining portion of the rod will reveal the average stress that existed in the removed layer. If the layers are taken small enough, the average residual stresses determined for each layer (and suitably corrected as noted in the following paragraph) will give a satisfactory step-like approximation to the actual residual stress pattern (Fig. 7).

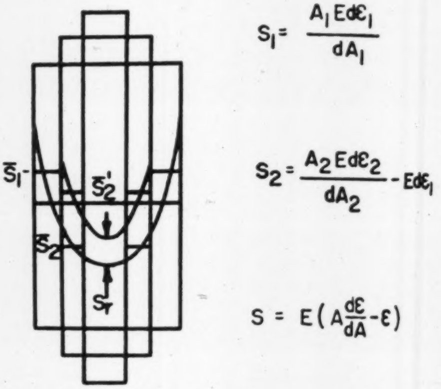

$S_1 = \frac{A_1 Ed\varepsilon_1}{dA_1}$
$S_2 = \frac{A_2 Ed\varepsilon_2}{dA_2} - Ed\varepsilon_1$
$S = E\left(A\frac{d\varepsilon}{dA} - \varepsilon\right)$
$\bar{S}_1$
$\bar{S}_2'$
$\bar{S}_2$
S_r

FIG. 8.—Removing the First Layer of a Rod Shifts the Stress in the Remainder of the Bar (by an Amount S_r).

Thus if a second layer is removed and Eq. 1 of the text is applied, it would yield a stress, S_2', that existed in the second layer in the original rod by an amount S_r. The shift in stress is uniform across the bar *unless the shift carries the remaining residual stress into the plastic region.* No treatment has been developed for these cases.

A complication arises, however, in applying Eq. 1 to a succession of removals. This will become immediately apparent: a single thin layer is removed from the rod; Eq. 1 is applied to determine the average residual stress in the removed layer; a second layer is removed from the rod; Eq. 1 is applied to determine the average residual stress in the second removed layer; *but the stress so determined will be the stress in the original bar in the second layer plus (or minus) the stress which was relieved throughout the remaining portion of the bar when the first layer was removed, that is,* S_r (Fig. 8). Thus the stress in the second layer as it originally existed in the rod is given by

$$S_2 = \frac{A_2 E \, d\epsilon_2}{dA_2} - E \, d\epsilon_1 \ldots\ldots (2)$$

in which the first term of the right-hand side of the equation gives the stress in the second layer prior to its removal and the second term is the correction for stress relieved by the removal of the first layer. It should be realized that the second term in Eq. 2 should account for the stress relief effected by all removals prior to the removal to which the first term applies. Thus, if the twentieth removal is made and Eq. 2 is being applied, it would appear as

$$S_{20} = \frac{A_{20} E \, d\epsilon_{20}}{dA_{20}} - E(d\epsilon_1 + d\epsilon_2 + \cdots d\epsilon_{19}) \,..(3)$$

If layers were removed in "differential sizes" Eq. 3 would read

$$S = E\left(A \frac{d\epsilon}{dA} - \int d\epsilon\right) = E\left(A \frac{d\epsilon}{dA} - \epsilon\right) \,..(4)$$

In practice, the equation can be applied in this form: finite layers are removed from the rod; the total strain, ϵ, existing after each removal is plotted as a function of the area of the remaining rod; a smoothed curve is drawn through the plotted points; the stress at any point in the rod is obtained by inserting A, ϵ, and $d\epsilon/dA$ in Eq. 4, the first two quantities being read directly from the curve, the last being determined as the *slope* of the curve at the point in question (Fig. 9).

This technique, attractive as it seems, is, however, only an approximation, and one which as we shall see has been shown in one experimental case to be in error by as much as 30 per cent!

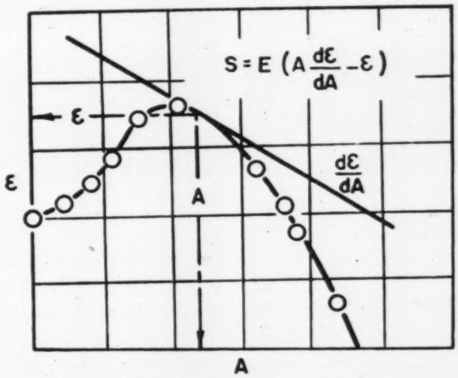


FIG. 9.—Graphical Method for Determining the Residual Stress in a Rod by Bauer and Heyn's Method.

The total strain, ϵ, existing after each removal is plotted as a function of the area of the remaining rod; a smoothed curve is drawn through the plotted points; the stress at any point in the rod is obtained by inserting A, ϵ, and $d\epsilon/dA$ in the equation shown in the graph.

In the general case, for example, a cylindrical bar will not possess longitudinal residual stresses alone but will contain circumferential stresses and radial stresses as well. These stresses can seriously affect the strain measurements made in Bauer and Heyn's method. For the moment let us consider a cylindrical bar in which the outer hull is subjected to *tangential* tensile stresses alone and the core is reacting under *tangential* compressive stresses alone. In this instance, the core will suffer something of the same deformations as a well-corsetted lady—the tangential tensile stresses in the outer case serve to slim and lengthen the core. The removal of the outer case by machining or other means will cause the core to relax—to expand and shorten. If now we presume a cylindrical bar to be subjected to tensile residual stress in both the longitudinal and tangential directions in the outer case and to be subjected to compressive residual stresses in both the longitudinal and tangential directions, in the inner core, it will be seen that the removal of the outer case will cause the inner core: (a) to tend to lengthen because of the release of the longitudinal restraint as in Heyn's spring analogy and (b) to tend to shorten because of the release of the tangential (corsetting) restraint. Thus the core will lengthen to a lesser extent when tensile tangential stresses are in the skin than when they are absent. Bauer and Heyn's method by ignoring the *tangential* tensile stresses will thus underestimate the *longitudinal* tensile stresses. The reader can readily assemble simple combinations of spring and corset analogies to see that the arithmetic value of the longitudinal stress will be underestimated by Bauer and Heyn's method when longitudinal and tangential stresses of like sign (tension-tension or compression-compression) coexist in the same region—for example, the outer hull—whereas it will be overestimated by this method when longitudinal and tangential stresses of opposite sign (tension-compression, or compression-tension) coexist in the same region.

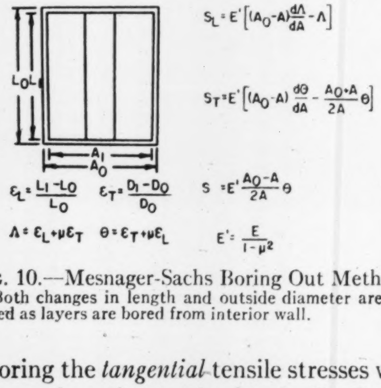

L_O
L
A_1
A_O
$S_L = E'\left[(A_O - A)\frac{d\Lambda}{dA} - \Lambda\right]$
$S_T = E'\left[(A_O - A)\frac{d\Theta}{dA} - \frac{A_O + A}{2A}\Theta\right]$
$\varepsilon_L = \frac{L_1 - L_O}{L_O}$
$\varepsilon_T = \frac{D_1 - D_O}{D_O}$
$S = E'\frac{A_O - A}{2A}\Theta$
$\Lambda = \varepsilon_L + \mu\varepsilon_T$
$\Theta = \varepsilon_T + \mu\varepsilon_L$
$E' = \frac{E}{1 - \mu^2}$

FIG. 10.—Mesnager-Sachs Boring Out Method. Both changes in length and outside diameter are observed as layers are bored from interior wall.

The perturbations produced by the transverse stresses on the determination of longitudinal stresses by Bauer and Heyn's method were early (1919) recognized by Mesnager (**8**) who proposed the experimental methods and adduced the equations—now more popularly known under the name of the Sachs (**9**) boring-out method (1927)—necessary for the complete and accurate determination of all three residual stresses,—the longitudinal, the tangential, and the radial,—in circular cylindrical rods or bars. In this method it is assumed that all three stresses can exist. It is further assumed that the stresses do not vary along the length of the bar nor around the circumference of the bar, but rather that the stresses vary only in the radial direction. These latter assumptions, although restrictive, are not unreasonable: bars or rods possessing residual stresses due to cold drawing, for example, would be expected to show uniform effects along the length of the bar because of the continuous or steady nature of the drawing operation; at the same time, because of the rotational symmetry of the circular cross-section, it would be expected that there would be no variation around the circumference of the rod.

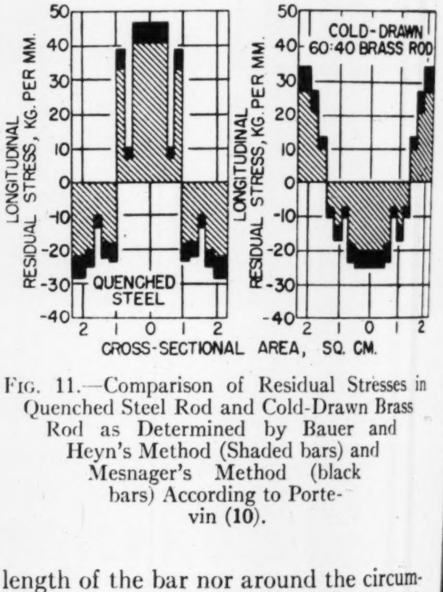


FIG. 11.—Comparison of Residual Stresses in Quenched Steel Rod and Cold-Drawn Brass Rod as Determined by Bauer and Heyn's Method (Shaded bars) and Mesnager's Method (black bars) According to Portevin (**10**).

Mesnager proposed the ingenious method of boring out the center of a cylinder in a succession of small layers and measuring resultant changes in both the length and outside diameter after each bore (Fig. 10).

Sachs showed that if the longitudinal strain, ϵ_l, and tangential strain, ϵ_t, are assembled into the parameters

$$\Lambda = \epsilon_l + \mu\epsilon_t$$

$$\Theta = \epsilon_t + \mu\epsilon_l$$

where μ is Poisson's ratio, the three residual stresses, longitudinal, s_l, tangential, s_t, and radial, s_r, can be expressed by equations similar in form to Bauer and Heyn's:

$$s_l = E'\left[(A_0 - A)\frac{d\Lambda}{dA} - \Lambda\right]$$

$$s_t = E'\left[(A_0 - A)\frac{d\theta}{dA} - \frac{A_0 + A}{2A}\theta\right] \quad .(5)$$

$$s_r = E'\frac{A_0 - A}{2A}\theta$$

$$\text{where } E' = \left(\frac{E}{1 - \mu}\right)^2$$

The first term within the brackets on the right-hand side of the equations corresponds to the stress relieved during removal of the nth bore, the second term corresponds to the stress relieved by all previous cuts. This technique can be applied with equal ease to tubes as well as solid bars or rods.

Mesnager points out that similar equations can be derived for an experimental method in which the outer diameter of the rod is machined off, the change in diameter of the bored-out hole being recorded. In this case the equations (using Sachs' form) are

$$s_l = E'\left[(A - A_h)\frac{d\Lambda}{dA} - \Lambda\right]$$

$$s_t = E'\left[(A - A_h)\frac{d\theta}{dA} - \frac{A + A_h}{2A}\theta\right] \quad .(6)$$

$$s_r = -E'\frac{A - A_h}{2A}\theta$$

where A_h is the cross-sectional area of bored hole.

Comparison studies using both Bauer and Heyn's method and the Mesnager-Sachs' boring-out method have been made. Portevin (10) for example, used both methods to determine the longitudinal stresses in a drawn 60–40 brass rod (in which case, as we shall see, longitudinal and tangential stresses are both tensile in the outer hull of the rod—the radial stresses being small—and both compressive in the inner core of the rod—the radial stress in this case also being compressive) and in a quenched steel bar (in which case longitudinal and tangential stresses are both compressive in the outer case of the bar—the radial stresses being small—and all three stresses tensile in the center of the bar), and finds in accordance with what was said above that Bauer and Heyn's method leads to an underestimate of the stresses in the amount of 30 per cent under the conditions of his experiments (Fig. 11).

Analogous methods of determining the residual stresses in objects where the residual stresses vary in one Cartesian direction only, but are constant in the other two,[5] have been developed by Stäblein (11), Davidenkow (11) and by Sachs and Espey (12). An example of the residual stress pattern that can be determined by this method would be one in which longitudinal residual stresses vary throughout the thickness of a strip—being tensile, let us say, at the two surfaces of the strip but compressive in the interior—but remaining constant along the length or width of the strip. Heyn's spring analogy can be applied here: the tensile stresses in the surface

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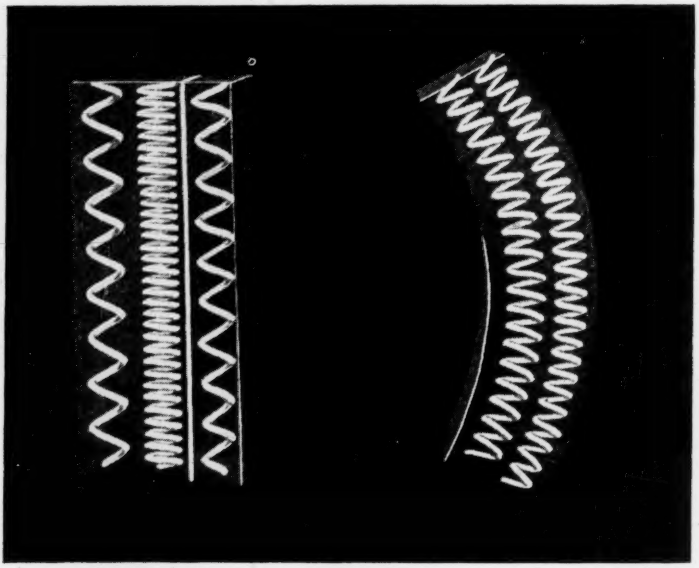
[5] The methods discussed so far have been confined to cases where the residual stresses vary along one cylindrical coordinate (the radial coordinate) but are constant along the other two (the axial and tangential).



(*a*) (*b*)

FIG. 12.—Heyn's Spring Analogy Applied to Davidenkow's Residual Stress Determination Method.
(*a*) Represents an object in which residual stresses vary in one direction only. For illustrative purposes, it is presumed that the center of the object is in compression and that the two edges are in tension. If one side of the object is removed the remainder will bend in the manner shown in (*b*).

layers of the strip can be thought of in terms of stretched springs, the compressive stresses in the central layers of the strip in terms of bunched springs, both sets of springs being fixed to crossheads at either end (Fig. 12). The removal of one surface spring will allow the remaining two springs to bend the strip, and the amount of this deflection will indicate the force of the spring which had restrained them. The method can be carried out by removing a succession of thin layers, just as in Bauer and Heyn's method, and plotting the total deflection, f, in a given length, l, obtained after each removal as a function of thickness, t. These quantities together with the slope of such a curve, df/dt, will yield the residual stress s_t at any value of thickness, t according to the equation

$$s = s_a - s_b - s_c \ldots\ldots. (7)$$

where

$$s_a = \frac{4}{3}\,\frac{Et^2}{l^2}\,\frac{df}{dt} \ldots\ldots. (7a)$$

$$s_b = \frac{4Etf}{l^2} \ldots\ldots\ldots (7b)$$

$$s_c = \frac{1}{t}\int (s_a - s_b - s_c)\,dt \,.\,. (7c)$$

In Eq. 7, the first term, s_a, represents the stress in the layer just removed while the second and third members (s_b and s_c) represent the corrections for stresses relieved by removal of previous layers due to bending and lengthening respectively.

It will be noticed that Eq. 7*c* is not explicit in s_c and Eq. 7 must be solved by an approximation method.[6]

An exact analysis of the residual stresses existing within a metal requires in general a large number of machining

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[6] Thus s_a and s_b are determined from the experimental data by Eq. 7*a* and 7*b*. Their difference is inserted in Eq. 7 to give an approximate value of s. This value of s is plotted as a function of t and the integration in Eq. 7*c* is performed (note that the quantity enclosed in parentheses is equal to s) to obtain an approximate value of s_c. The values of s_a, s_b, and s_c are now entered in Eq. 7*c* to obtain a new approximate value of s, and so on. Fortunately, the correction is an oscillating one, and two approximations usually serve to give highly accurate results.

(or pickling) operations, and a large number of dimensional measurements. A complete analysis of a single specimen can take upwards of 50 man-hours. A general investigation into the effects of the variables involved in a given forming operation on the residual stresses developed may involve something of the order of 70 or 80 specimens (see Fig. 35 or 40 for example). The prospect of the 3000 to 4000 man-hours required for exact residual stress determination in such an investigation makes the most persevering investigator blanch. Understandably enough, there is therefore a strong drive to develop time-saving short-cuts of oversimplification (and distortion) of results. This has been tolerated in the development of our understanding of residual stresses: we have been willing to accept some oversimplification in the interest of setting up a rough embracing scaffold of general knowledge in this field. So many of our present data have been obtained by such methods in fact, that it is important to realize the distortion that is involved in these data, and a review of the approximate methods of residual stress determination becomes mandatory.

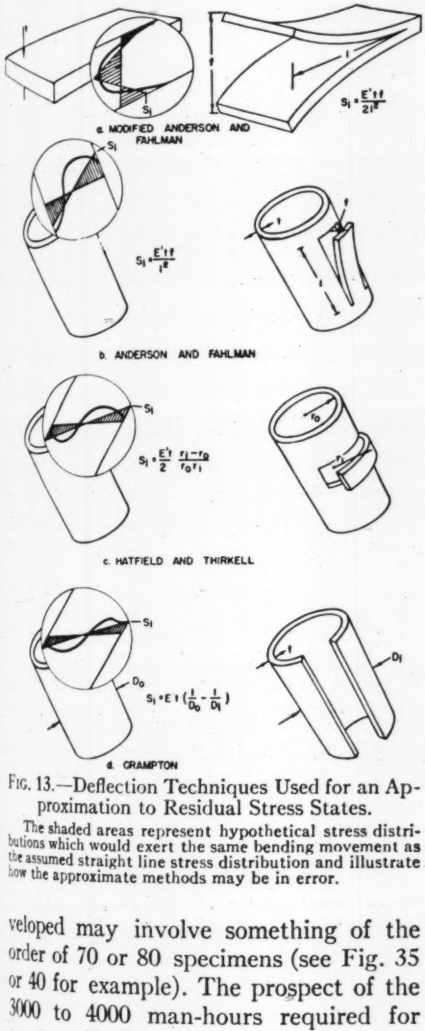
S_1
$S_1 = \frac{E' t f}{2l^2}$
a. MODIFIED ANDERSON AND FAHLMAN
S_1
$S_1 = \frac{E' t f}{l^2}$
b. ANDERSON AND FAHLMAN
S_1
$S_1 = \frac{E' t}{2} \frac{r_1 - r_0}{r_0 r_1}$
r_0
r_1
c. HATFIELD AND THIRKELL
S_1
D_0
$S_1 = E t \left(\frac{1}{D_0} - \frac{1}{D_1}\right)$
D_1
d. CRAMPTON

FIG. 13.—Deflection Techniques Used for an Approximation to Residual Stress States.

The shaded areas represent hypothetical stress distributions which would exert the same bending movement as the assumed straight line stress distribution and illustrate how the approximate methods may be in error.

DEFLECTION TECHNIQUES

Where residual stresses are thought to vary through the thickness of a plate or shell but are believed to remain constant along the length of the piece (because of the continuous process by which the part was produced) and across the width of the plate or around the circumference of the shell (because of conditions of symmetry or other reasons), a variety of approximate techniques may be applied all involving the deflection of a length of the plate or shell. One such approximate method is applied to rolled strip, for example, in the following manner.

The strip is split down its central plane (Fig. 13). The two halves of the strip curl back, thereby releasing whatever bending moment existed in the two halves before splitting. This bending moment according to the usual theory of beams is

$$M = \frac{E'I}{\rho}$$

where:

$E' = E/1 - \mu^2$,
E = Young's modulus of elasticity,
μ = Poisson's ratio,
I = moment of inertia of the split section, and
ρ = radius of curvature.

The actual residual stress distribution that went to make up this bending moment is unknown, but for the sake of simplicity it is assumed that the stresses were distributed according to the straight-line function shown in Fig. 13(*a*). In this case, the formula for the stress, s, at an external surface of a bent beam may be applied, that is,

$$s = \frac{Mt}{I}$$

where t is the thickness of the beam, which gives

$$s = E' \frac{t}{2} \frac{f}{l^2} \ldots\ldots\ldots (8)$$

where f is the deflection of the curled section and l is its length.

This stress may be either lower or higher than that that actually exists at the external surface of the strip as shown in Fig. 13.

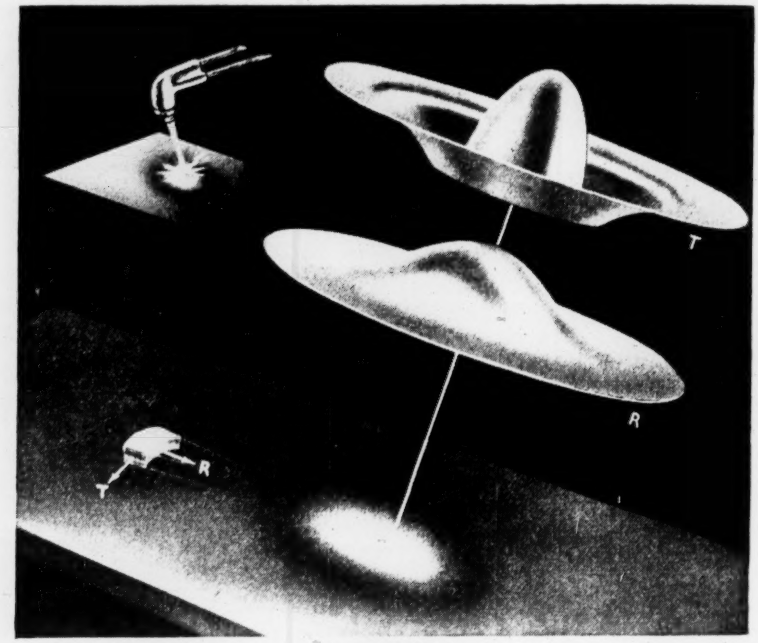

FIG. 14.—Residual Stress Pattern Found in Strip Heated Locally.

In the lower picture the direction in which the radial stresses, *R*, and tangential stresses, *T*, operate are defined. The intensity of the radial stress at different points throughout the strip is shown in the three dimensional graph immediately above the strip: the stresses are tensile at the center of the affected zone and drop off to a negligible value at some distance from the affected zone. The intensity of the tangential stress at different points throughout the strip is shown in the uppermost chart: the stresses are tensile at the center of the affected zone, drop to a compressive value immediately outside of the affected zone and then fall off to a negligible value at some distance from the affected zone.

Other approximate techniques that involve the measurement of deflection of a "beam" and involve oversimplification due to an assumed linear distribution of stresses throughout the thickness of the beam are given in Fig. 13. In subsequent sections where data were obtained by approximate techniques, the stresses so reported will be termed approximated residual stresses and the technique by which they were obtained will be given by the name employed in Fig. 13.

LOCAL STRAIN TECHNIQUES

In other cases, the variation of residual stress over the plane of a plate or shell is thought to be more important than any such variation through the

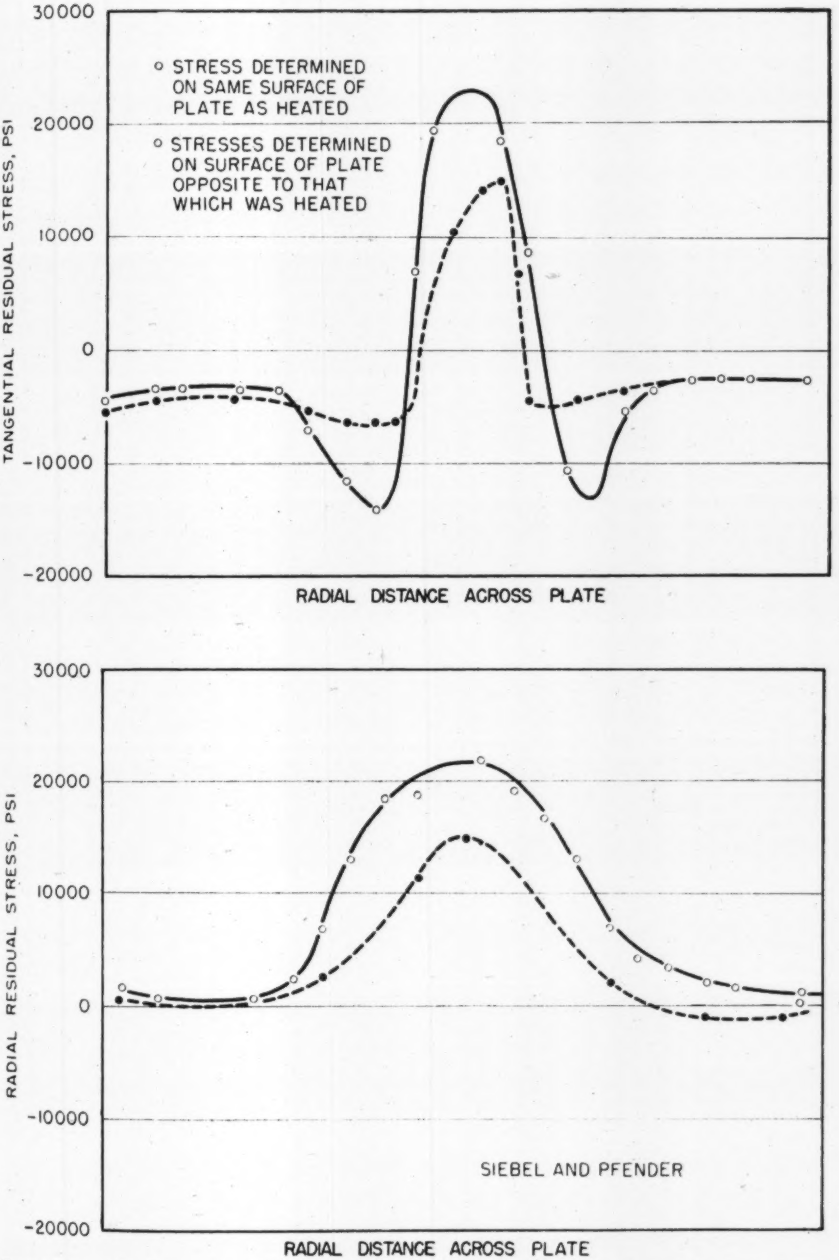

FIG. 15.—Residual Stress Distribution in a Strip Heated Locally and Cooled (According to Siebel and Pfender) (**16**).

The plate dimensions were 17¾ by 17¾ by 1.18 in. The material was mild steel. The yield point of the steel was not reported in the immediate discussion of this experiment although the mild steels used in other experiments reported in their paper had yield strengths of 36,000 to 37,000 psi. The strip was heated with a torch to "the beginning of red heat" (probably around 1100 or 1200 F.) then air cooled. No estimate of the diameter of the heated zone was given. No abscissas are reported in the original paper. A local strain technique was used in determining the stresses. The stresses reported here are therefore average stresses throughout the thickness of the strip.

thickness and a variety of local strain techniques can be applied in this instance. In these techniques (16) some region of the plate is removed and the strains on the surface of the plate (either in the removed region or an adjacent region) are suitably measured. These strains are then converted to stresses through Hooke's law using the general equations:

$$\epsilon_x = \frac{s_x}{E} - \frac{\mu}{E}(s_y + s_z)$$

$$\epsilon_y = \frac{s_y}{E} - \frac{\mu}{E}(s_x + s_z) \quad \ldots\ldots (9)$$

$$\epsilon_z = \frac{s_z}{E} - \frac{\mu}{E}(s_y + s_z)$$

Siebel and Pfender (16), for example, impressed gage marks in two perpendicular directions (x and y) on the surface of plates, cut the plates into strips and measured the resulting changes in gage lengths. From the strains so measured, the stresses in the x and y directions were determined by the equations:

$$s_x = \frac{E}{1 - \mu^2}(\epsilon_x - \mu\epsilon_y)$$

$$s_y = \frac{E}{1 - \mu^2}(\epsilon_y - \mu\epsilon_x)$$

which follow directly from Eq. 9.

These local strain techniques are approximations in that the residual stress so determined represents either the stress at the plate surface or an average stress throughout the thickness of the plate (depending upon the exact details of the technique) but gives no description of the actual residual stress at each point throughout the thickness of the plate.

It should be noted here that the various X-ray techniques of determining residual stresses are all local strain techniques; the X-ray merely determines the elastic strain at the metal surface. These techniques (17), since they measure only elastic strain—and that directly—do not require segmenting, and therefore destroying, the metal parts to be tested.

RESIDUAL STRESS PATTERNS

Having seen how residual stresses are measured we may now address ourselves to a review of the residual stress patterns that exist in metals. Obviously, because of the tremendous number of residual stress patterns that can possibly arise from the numerous casting, welding, heat treatment, and working techniques, only a selected representative group can be discussed here.

RESIDUAL STRESS PATTERNS ARISING FROM THERMAL EFFECTS

Flat Plates:

Residual stresses are developed in a flat plate that is heated locally and allowed to cool, as for example in spot welding (Fig. 14).

The stress distribution for this case was first investigated by Siebel and Pfender (16) using a local strain technique. These authors report the stress distribution shown in Fig. 15. It should be borne in mind that the radial and tangential stresses reported in this chart are actually the radial and tangential stresses derived from strains measured at the surface of the strip and not necessarily those that exist throughout the thickness of the strip. In thin sheets it is probable, however, that Siebel and Pfender's distribution is reasonably uniform throughout the thickness of the strip. Simple rationalizations of this type of stress distribution have been given. In deference to their priority, we quote Siebel and Pfender themselves. "On heating," these men write, "the material in the hot localized zone seeks to expand. Since any expansion in the plane of the plate is restrained by the surrounding cold material and since simultaneously the yield strength in the localized zone is lowered, a permanent compression in the tangential and radial directions with a simultaneous increase in thickness sets in. This compression is preserved on subsequent cooling. Since, however, the outer zones restrain the thermal contraction of the localized zone, the latter takes on elastic tensile stresses in both the radial and tangential directions, whereas the outer zones simultaneously are elastically elongated in the radial direction, but compressed in the tangential direction."

Of course, such a simple explanation assumes, among other things, that all the participating factors are constant throughout the thickness of the strip at any given point.

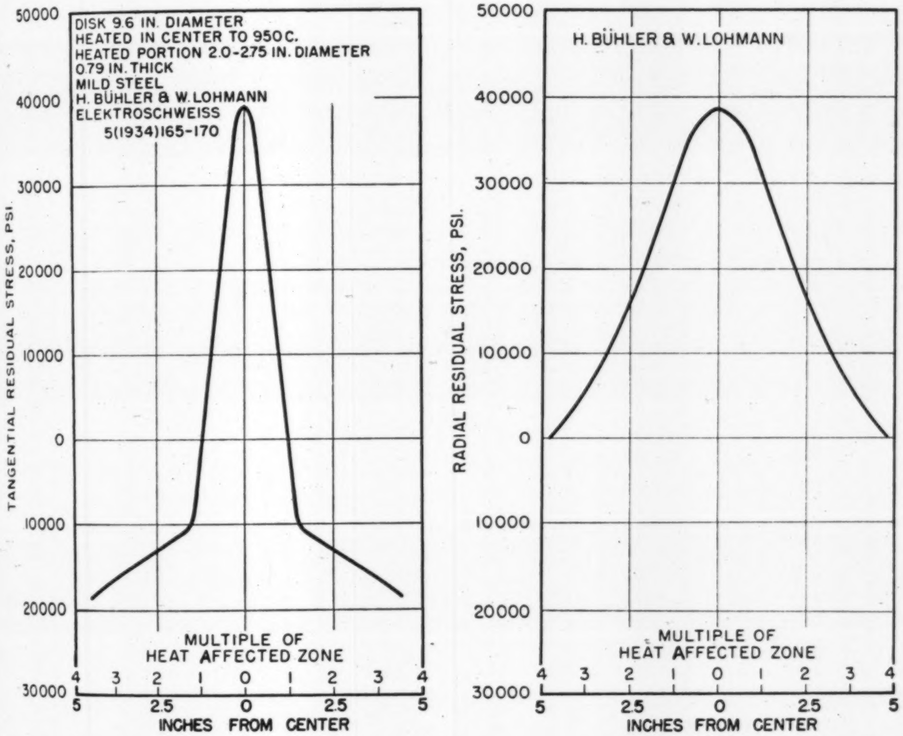

FIG. 16.—Residual Stress Distribution in a Strip Heated Locally and Cooled (According to Bühler and Lohmann) (18).

The specimen was a mild steel (yield strength, 38,000 psi.) 0.73-in. thick disk, 9.6 in. in diameter. The strip was heated with a torch to about 1750 F. (950 C.) in a central circular area 2 to 2¾ in. in diameter and air cooled. Sachs' boring-out method was used to determine the stress. It should be remembered that this method assumes that stresses are constant in the direction of the axis of boring (in this case through the thickness of the plate). Since this is not necessarily the case here, the stresses reported are *average* stresses throughout the thickness of the plate.

Siebel and Pfender's results have been corroborated by Bühler and Lohman (**18**) (using Sachs' boring-out method) as may be seen in Fig. 16 and by Rosenthal and Norton (**19**) (using X-rays, a surface technique), as shown in Fig. 17.

Residual stresses are developed in flat

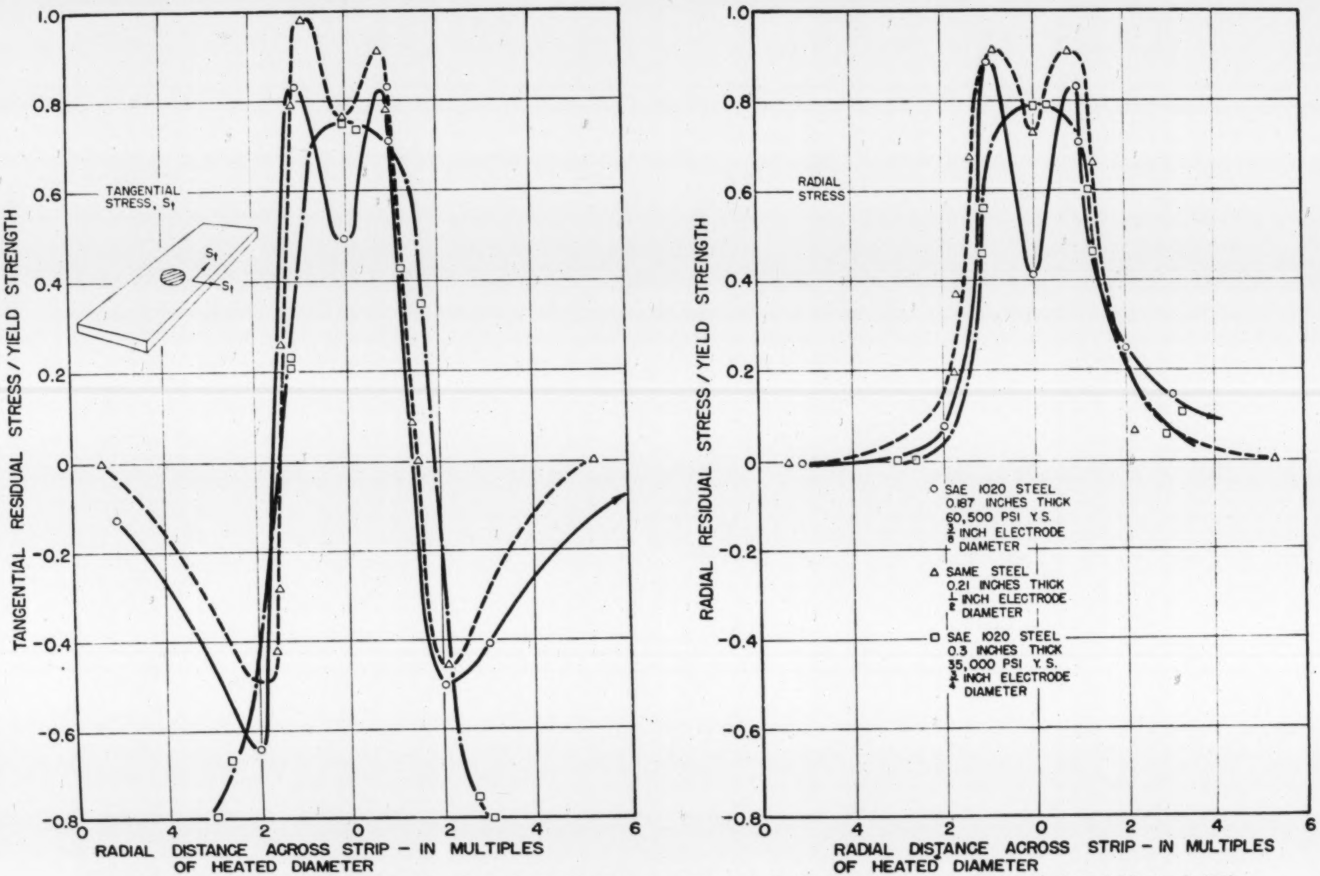

FIG. 17.—Residual Stress Distribution in a Strip Heated Locally and Cooled (According to Rosenthal and Norton) (19).

The plates were to 15 in. long by 3 in. wide in various thicknesses (indicated in the charts). A number of mild steels with various yield strengths (indicated in the charts) were used. The strips were heated in a resistance welder to accurately recorded temperatures in the range of 1500 to 1700 F. The diameters of the heated zones were varied (indicated in the charts). It is to be noted that in some instances the diameter of the heated zone constituted a considerable portion of the width of the plate. The depressions in the central portions of some of the curves are attributed to overheating of the steels by the electrode. The stresses were measured by an X-ray technique (J. T. Norton and D. M. Loring, "Stress Measurement in Weldments by X Rays," *The Welding Journal*, Research Supplement, Vol. 20,

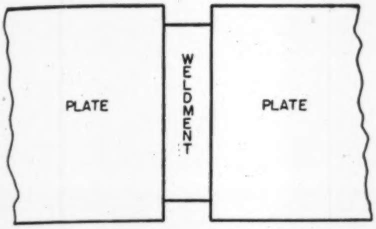

FIG. 18.—Simplified View of the Mis-Match Occurring in a Butt-Welded Joint of two Free Flat Plates.

The weldment (and immediate environs) is naturally shorter than the gap between the two plates. A compatible match is made in which the two plates are compressed along their welded length and the weldment elongated.

plate that is heated along a line and allowed to cool (as for example in butt welding).

If the plate is free, the mismatch consists, in the most simplified view, in a thin strip of metal being naturally shorter than the length it must fill (Fig. 18). This situation arises from the fact that when

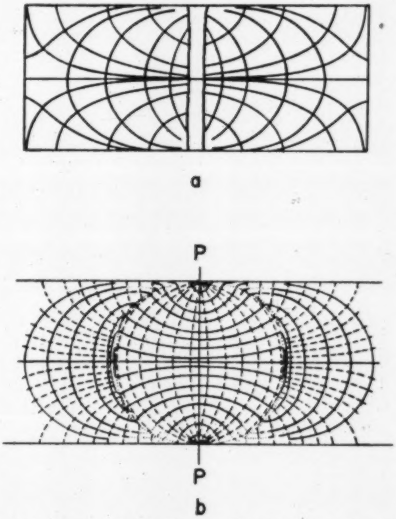

FIG. 19.—Principal Stress Trajectories in (*a*) a Butt Arc-Welded Assembly (Mies (**20**)) and (*b*) a Flat Plate Being Pinched Between two Concentrated Loads (Mesmer (**21**)).

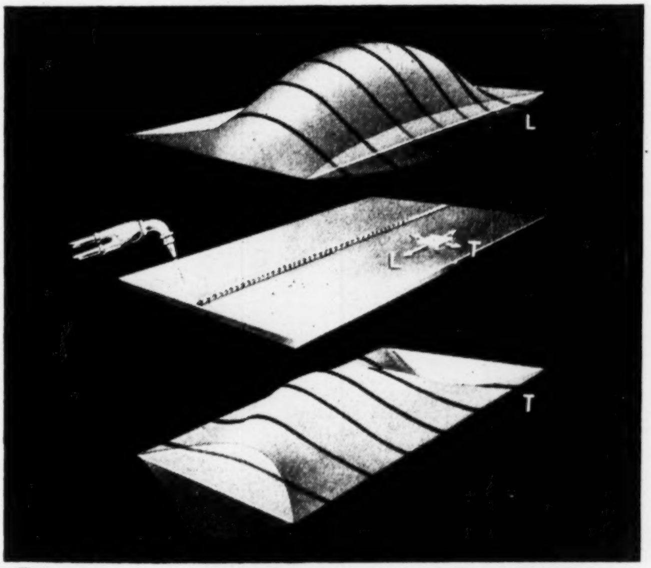

FIG. 20.—Residual Stress Pattern Found in a Butt Welded Strip.

The middle drawing helps define what is meant by longitudinal stresses, *L*, and transverse stresses, *T*. The variation of the longitudinal stresses, *L*, is shown in the upper drawing; that of the transverse stresses, *T*, is illustrated in the lower drawing. In these charts, points plotted above the white reference planes represent tension, those below represent compression.

hot the heated zone expands, but being restrained in length by the cold portions[7] it is shortened, the yield strength being low at high temperatures.

It might be thought that such a mismatch would create only longitudinal residual stresses (stress parallel to the hot zone), but such is not the case. The manner in which the hot zone will shorten the neighboring plates is somewhat germane to the behavior of a plate being compressed between two equal and opposed concentrated forces. It is true that the hot zone is under longitudinal tension whereas the line joining two concentrated compressive forces is in compression. The action of these two areas on metal somewhat removed from these "center-lines" is analogous, however, and by St. Venant's principle the stresses in these regions should be similar. It is not surprising, therefore, that the principal stress trajectories in a butt-welded plate bear certain similarities to those in a strip being pinched (Fig. 19).

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[7] Any lateral expansion of the hot zone can occur without restraint under the assumption that the plate is free.

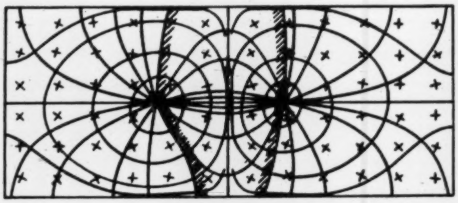


FIG. 21.—Principal Stress Trajectories in a Butt-Torch-Welded Assembly (Mies (**20**)).

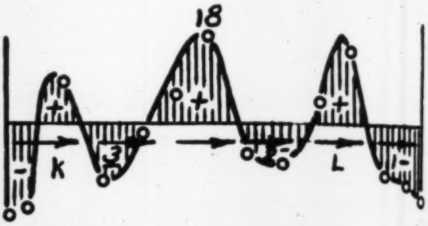
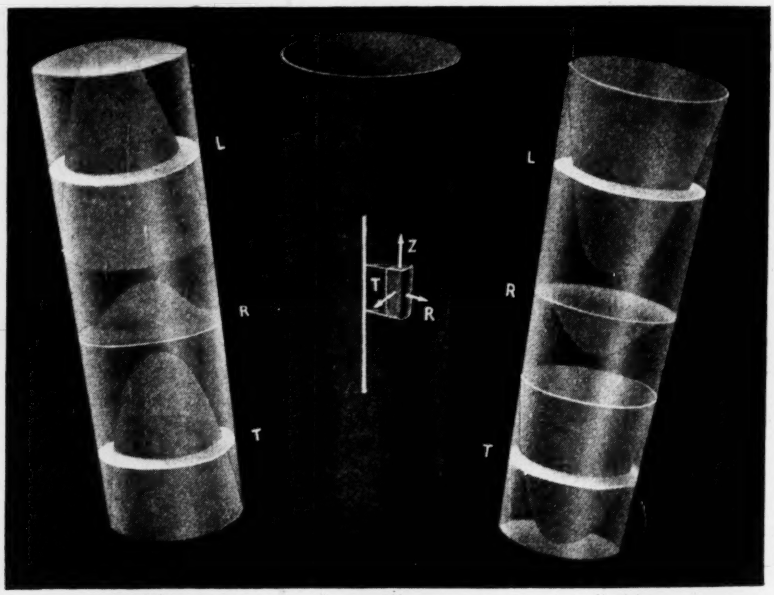


FIG. 22.—Longitudinal Residual Stresses in an Intermittent Butt-Welded Assembly (Bierett (**22**)).



(*a*) (*b*) (*c*)

FIG. 23.—Idealized Residual Stress Patterns Found in Quenched Cylindrical Bars.

In (*b*) the directions in which the longitudinal stresses, L, the tangential stresses, T, and the radial stresses, R, ar are defined. (*a*) is a three-dimensional chart showing the stress distribution found in quenched bars which undergo only normal contraction on cooling: the longitudinal stresses, L, at the surface of the bar are compressive (compressive stresses are indicated by points below the reference cross-section) rising to highly tensile values at the axis of the bar (tensile stresses are indicated by points above the reference cross section); radial stresses, R, are nil at the surface of the bar and rise to tensile values at the axis of the bar; tangential stresses, T, follow a pattern similar to that of the longitudinal stresses. (*c*) is a similar chart showing the stress distribution found in quenched bars that expand on cooling: the stress distributions are reversed from those found in the normal case.

With the exception of Mies (**20**), those investigators (**22**) who have studied residual stresses in butt-welded assemblies have not reported their data as principal stresses but rather as longitudinal and transverse stresses. Since these stresses do not coincide with the principal stresses, it is to be understood that shear stresses will also occur on planes in the longitudinal and transverse directions. The type of distribution of longitudinal and transverse stresses in free continuously butt-welded assemblies is indicated in the charts shown in Fig. 20. The data of Siebel and Pfender (**16**), and a host of other investigators (**22**) are all of this type though showing some variations with welding details. Thus, arc welding which generally produces a relatively localized heating narrows the region in which longitudinal stresses are tensile, whereas this region is broader in torch-welded assemblies (Fig. 21). Step-back welded assemblies show minor differences from continuous welded plates. Intermittent methods however produce residual stress patterns of a type quite different from that of continuous welding (Fig. 22).

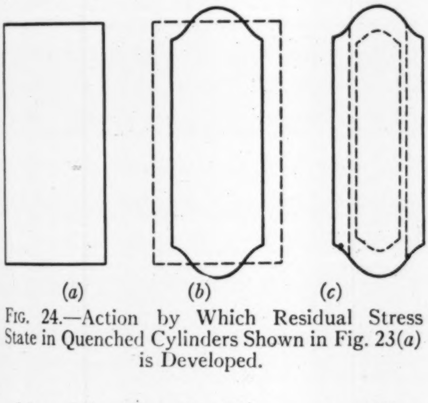

(*a*) (*b*) (*c*)

FIG. 24.—Action by Which Residual Stress State in Quenched Cylinders Shown in Fig. 23(*a*) is Developed.

Cylinders:

The residual stress patterns found in cooled or quenched cylinders are of interest since such shapes are frequently cast as well as heat treated. The general type of residual stress pattern found in quenched cylinders in which the metal contracts on cooling is shown in Fig. 23(*a*). Figure 23(*c*) shows the pattern found in metals that expand on cooling. It is seen that the two patterns are the opposite of each other. The patterns may be rationalized easily enough. In the former case, the outer annulus cools and contracts first, giving a ring that is shorter and smaller in diameter than its original diameter (Fig. 24(*b*)). This action serves to extrude the inner core plastically into a longer, thinner cylinder than it originally was, much as a child will squeeze mud out of his clenched fist (Fig. 24(*b*)). The inner core when it finally cools and contracts would, if free from the outer jacket, pass to a shorter and thinner cylinder (Fig. 24(*b*)). The mismatch responsible for the residual stresses consists, then, in an oversized case and an undersized center. To maintain compatibility, the jacket is drawn in longitudinally, radially, and tangentially, the core is drawn out in the same three directions, giving rise to the stress distribution shown in Fig. 23(*a*). A similar rationalization explains the pattern shown in Fig. 23(*c*) for a metal that expands on cooling. It should be noted that the cylinder may be bulged at its ends—evidence of the plastic extrusion which the central core suffered—and yet these contours give no clue to the residual stress state within the metal.[8]

TABLE I.—PROPERTIES OF METALS.

Metal	Yield Strength, psi.	Young's Modulus of Elasticity, psi.	Cubical Coefficient of Expansion	Inverse Diffusivity, per sq. cm.
Aluminum..	5 000	11 000 000	24×10^{-6}	0.05
Copper	8 000	15 000 000	17×10^{-6}	0.02
Iron	30 000	30 000 000	12×10^{-6}	0.1
Magnesium.	14 000	6 000 000	16×10^{-6}	0.3
Zinc........	15 000	13 000 000	22×10^{-6}	2.0

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[8] Hasty observation of the ends of the cylinder might lead one to conclude that the center of the cylinder being longer than the outer layers is being restrained by them and is therefore under longitudinal compression and that by natural reaction the outer layers are under longitudinal tension—a stress distribution just the reverse of that that actually exists.

The magnitude of the residual stress patterns shown in Fig. 23(*a*) (as, indeed, in any case) will depend on two broad factors: (1) the relationships that exist between stress and strain for the particular metal, and (2) the magnitude of the elastic adaption to the mismatch (strain).

1. Thus for a given mismatch (strain) a higher residual stress will obviously result if Young's modulus of elasticity is high. Similarly, the limiting value of residual stress will be higher, the higher the yield strength of the metal.

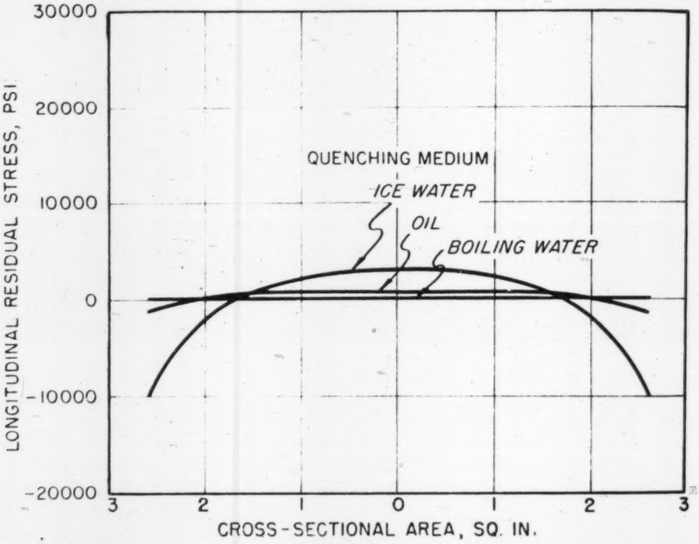

FIG. 25.—Longitudinal Residual Stresses Developed in Aluminum Rods Quenched from 480 F (Hopkins, Kempf, and Ivanso (**24**)), Bauer and Heyn's Method.

2. The larger the strain, the larger the residual stresses will be. Those factors that make for a large strain are seen to be:

(*a*) The form of the yield strength *versus* temperature curve for the metal in question. This function can well limit the temperature range in which elastic adaption to the mismatch occurs to such a narrow field that low stress results even though all other factors are favorable to high residual stresses. Thus, for example, a hypothetical metal might have a zero yield strength down to the temperature of boiling water and some high value from this temperature to room temperature. In this instance, the core would adapt itself to the case by plastic deformation down to 212 F. and only over the narrow temperature range, 212 to 70 F., would there be any elastic adaptation to give rise to residual stresses. Accordingly high residual stresses will result in metals that possess high yield strengths over large temperature intervals though a lowered yield strength at the temperature from which the metal is being quenched is necessary to permit the plastic flow that initiates the mismatch.

(*b*) A high thermal coefficient of expansion, α.

(*c*) A low thermal conductivity, κ.

(*d*) A high specific heat, c.

(*e*) A high density, ρ.

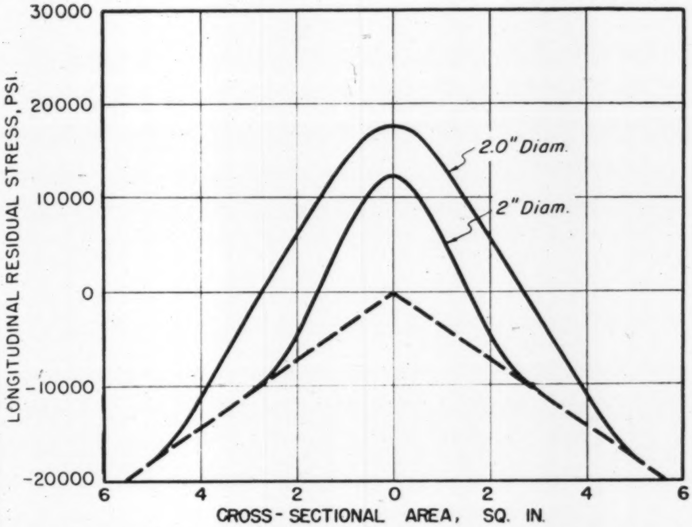

FIG. 26.—Longitudinal Residual Stresses Developed in 122 Alloy Rods Quenched from 480 F. in Ice Water Showing the Effect of Diameter on Magnitude of Stresses Developed. (Hopkins, Kempf, and Ivanso (**23**)), Bauer and Heyn's Method.

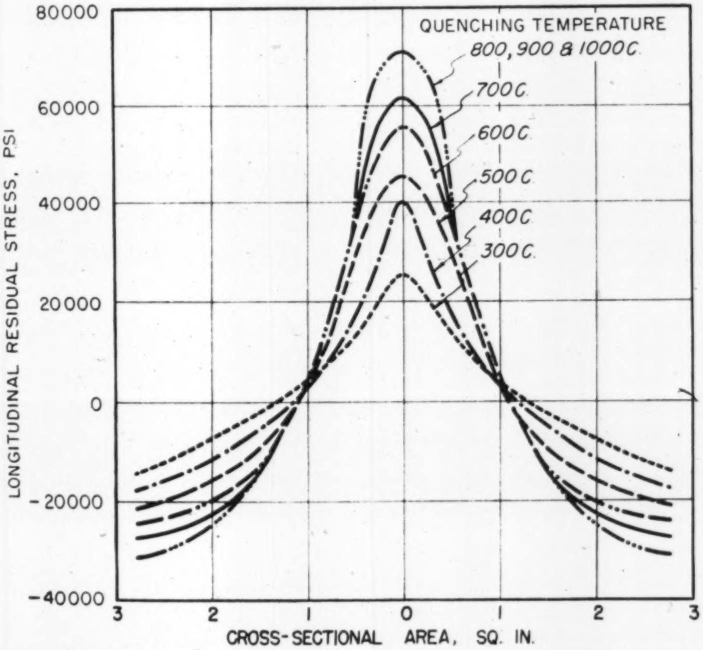

FIG. 27.—Longitudinal Residual Stresses Found in Steel Rods Quenched from Various Temperatures in Water. (Bühler and Scheil (**24**)), Mesnager-Sachs' Method.

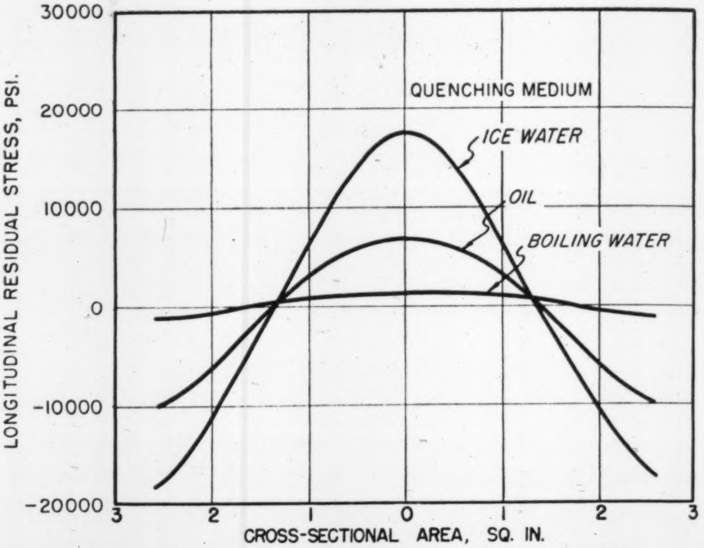

FIG. 28.—Longitudinal Residual Stresses Developed in 2.5-in. 122 Alloy Rods Quenched from 480 F. in Various Quenching Media Showing the Effect of Quenching Efficiency on Residual Stresses. (Hopkins, Kempf, and Ivanso (**23**)), Bauer and Heyn's Method.

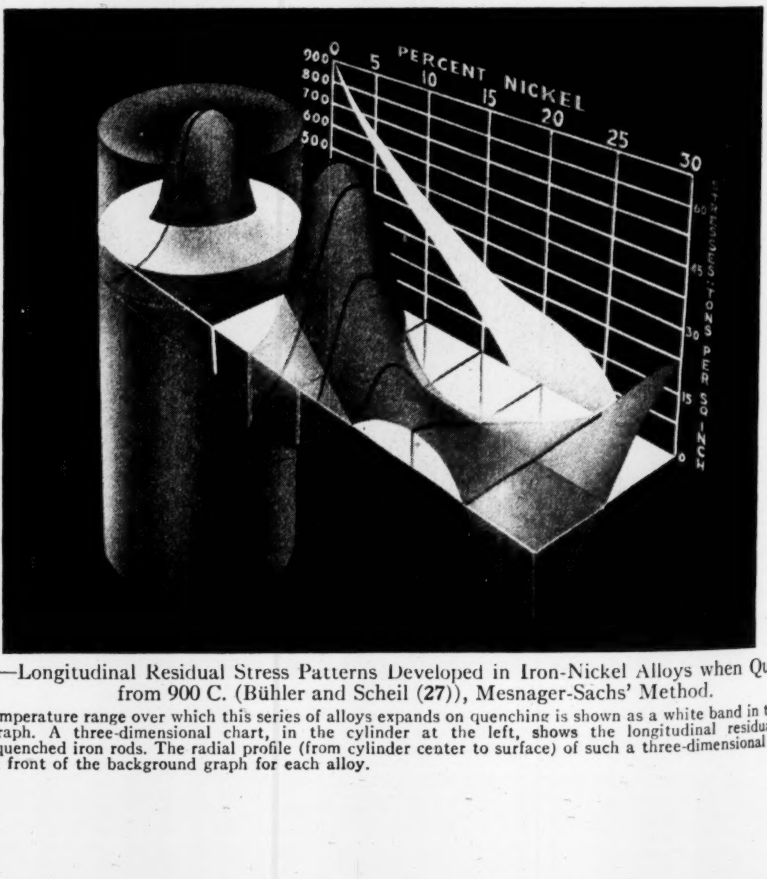

FIG. 29.—Longitudinal Residual Stress Patterns Developed in Iron-Nickel Alloys when Quenched from 900 C. (Bühler and Scheil (**27**)), Mesnager-Sachs' Method.

The temperature range over which this series of alloys expands on quenching is shown as a white band in the background graph. A three-dimensional chart, in the cylinder at the left, shows the longitudinal residual stress found in quenched iron rods. The radial profile (from cylinder center to surface) of such a three-dimensional graph is plotted in front of the background graph for each alloy.

These latter three factors may be assembled into the single factor inverse diffusivity, $\frac{1}{\lambda} = \frac{\kappa}{\rho c}$, which if high leads to a large mismatch.

(*f*) A large cylinder size.

(*g*) A large temperature difference on quenching.

(*h*) A high quenching efficiency.

It is seen that the factors under Paragraph 1 and the first five factors (*a* thru *e*) in Paragraph 2 are properties of the metal in question. In Table I, these properties are listed for five common metals. The low yield strength of copper and aluminum, for example, limit the residual stresses to low values, and it is therefore not surprising to find the residual stresses resulting from quenching these metals to be rather low (Fig. 25). The addition of alloying agents, however, to these metals as well as the rest serves, usually, to increase the yield strength and the inverse diffusivity[9], thus increasing the magnitude of residual stresses found on quenching (compare Figs. 25 and 28).

The latter three factors in Paragraph 2 are factors involved in the fabrication of the metal. As was pointed out, large cylinder sizes accentuate the residual stresses developed (see Fig. 26), and it is thus in quenching large sizes that particular skill and care must be exercised in heat treatment. In this case it might be necessary to use less drastic quenching,—either lowering the temperature from which quenching will be effected (Fig. 27), increasing the temperature of the quenching bath, or decreasing the efficiency of the quenching bath (Fig. 28). In aluminum alloys, for example, the quenching conditions necessary for the attainment of desirable properties is usually so mild that relatively minor residual stresses result.

So far the illustrations have been drawn from alloys that only contract when cooled. Similar examples could be cited for cases where the alloy only expands on cooling and which bear out the stress pattern shown in Fig. 23(*c*), but such cases have to be tailor made, for there is no known alloy that only expands (undergoing no contraction) on cooling. Such expansion usually results from a metallographic transformation which is confined to a limited temperature range, the alloy contracting in all other temperature ranges. In such cases there will be two opposing tendencies, and the ultimate residual stress pattern is usually a hybrid pattern developed from the two idealized patterns. The residual stress patterns developed on quenching iron-nickel cylinders from 900 C. illustrate this point (Fig. 29). The temperature range over which these alloys expand on cooling becomes broader and passes to a lower temperature in alloys having higher nickel contents. In pure iron and in the iron-rich alloys (up to 5 per cent nickel, for example) the alloys expand at high temperatures but then contract on further cooling over such a broad temperature range that they show the typical contraction-type residual stress pattern (Fig. 23(*a*)) on quenching (Fig. 29). Iron-nickel alloys having 20 to 25 per cent nickel expand at low temperatures, and this action serves to cancel any contraction which had occurred on cooling through the higher temperature ranges to given an expansion-type residual stress pattern (Fig. 23(*c*)) on quenching (Fig. 29). Alloys with nickel contents between these two ranges give hybrid-type residual stress patterns. Alloys with nickel contents above 25 per cent nickel do not transform on cooling to room temperatures and therefore show the idealized contraction-type residual stress pattern (Figs. 29 and 23 (*c*)).

Methods for calculating the residual stresses in quenched cylinders have been

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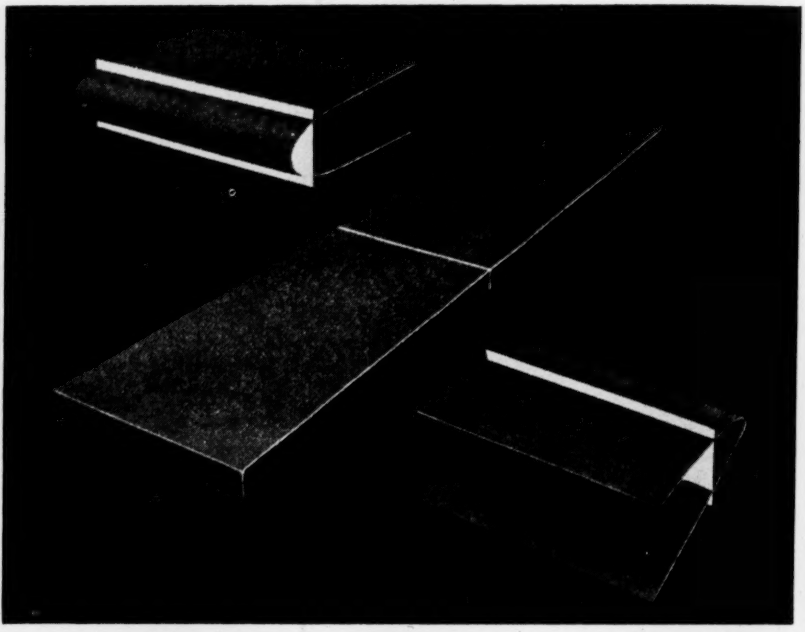
[9] Young's modulus of elasticity and the coefficient of expansion are usually affected to a lesser degree.



(*a*) (*b*) (*c*)

FIG. 30.—Two Types of Residual Stress Patterns Thought to Exist in Rolled Strip.

Residual stresses lying in the rolling direction will vary over any cross-section of the strip. In (*a*) the longitudinal stresses are compressive at the rolled surfaces (points on the three-dimensional chart behind the reference cross-sectional plane represent compression) and tensile in the interior of the metal. In (*c*) the longitudinal stresses are tensile at the polled surfaces and compressive in the interior of the metal.

presented by Hirone (**25**) and Kompaneets (**26**). They serve to illustrate the general relationship between the factors discussed above and the residual stresses that are developed on quenching but necessarily require a knowledge of the temperature distribution within the cylinder as a function of time, as well as a knowledge of the relation between yield strength (under multiaxial conditions) and temperature—two quantities difficult to evaluate with any degree of accuracy—if numerical data for the residual stress patterns are desired.

RESIDUAL STRESS PATTERNS ARISING FROM MECHANICAL EFFECTS

Residual stress patterns in cold-worked metals cannot be rationalized in all cases in the simple terms that were employed in the case of welded assemblies or quenched metals. This arises from the fact that the flow of the metal in a cold-working operation is not clearly

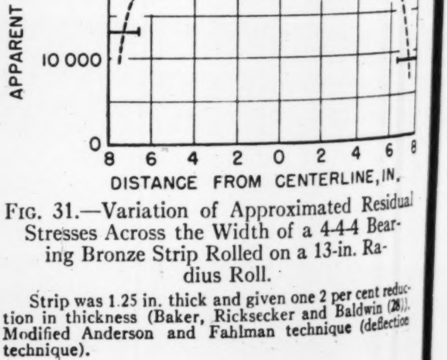


FIG. 31.—Variation of Approximated Residual Stresses Across the Width of a 4-4-4 Bearing Bronze Strip Rolled on a 13-in. Radius Roll.

Strip was 1.25 in. thick and given one 2 per cent reduction in thickness (Baker, Ricksecker and Baldwin (28)). Modified Anderson and Fahlman technique (deflection technique).

known in all cases, and it is difficult therefore to predict the exact nature of the mismatch which will produce the residual stress pattern.

Strip Rolling:

We wish to confine our remarks, at least for the moment, to true flat rolled strip, that is, to strip which has received a constant reduction in thickness at each point across the width of the strip. Frequently, either by intention or otherwise, strip will be rolled such that it suffers variable reductions in thickness from point to point across the width of the strip.

Two oversimplified residual stress patterns that are believed to result from true flat strip rolling are shown in Fig. 30.

In the stress distribution of the first type (Fig. 30(*a*)), longitudinal stresses (that is, stresses operating in the rolling direction) are compressive at and near the rolled surface and tensile on the mid-planes of the strip.

In the stress distribution of the second type (Fig. 30(*c*)), longitudinal stresses are tensile at and near the rolled surface and compressive on the mid-planes of the strip.

These patterns are oversimplified in at least two fundamental respects. In the first place no representation is made of the residual stresses operating in a direction across the width of the strip (transverse stresses) or in a direction perpendicular to the rolled surface of the strip (thickness stresses). While general considerations would indicate that the thickness stresses, at least in strip of the usual widths, would be negligibly small, the same cannot be said of transverse stresses. No data on the transverse stresses have ever been reported, and in

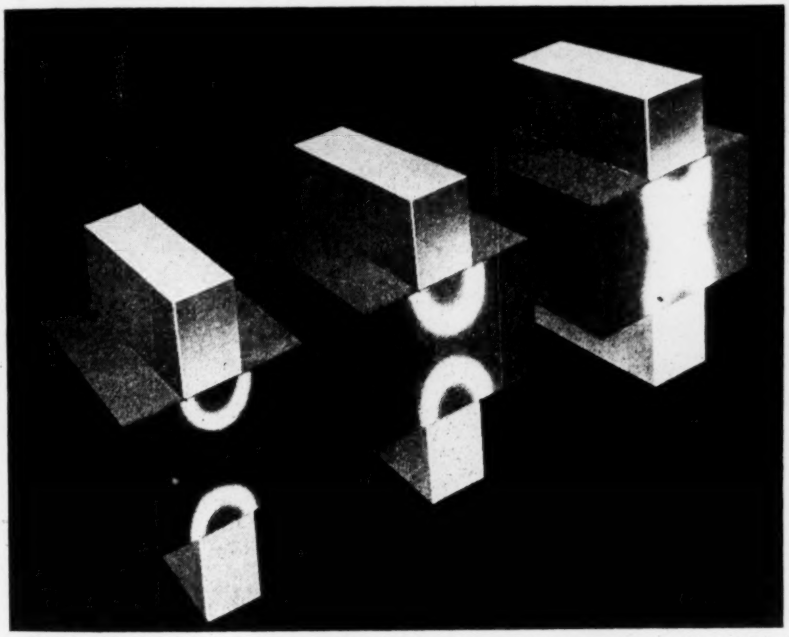


FIG. 32.—Manner in Which Plastic Flow is Initiated and Spreads Throughout a Metal Block Being Squeezed Between Flat-Faced Tools.

Plastic flow first occurs in the approximately semi-circular cylindrical region having the tool face as diameter (*a*). The region in which plastic flow occurs spreads out from this semi-circular region as the tools are pressed deeper into the metal block (*b*) and (*c*)).

the absence of definite information, no representation of transverse stresses has been made in Fig. 30.[10]

In the second place the distributions in Fig. 30 indicate that the stresses do not vary across the width of the strip. This is approximately true for relatively wide strip. Figure 31, for example, shows the (approximated) residual stresses across the width of a $15\frac{7}{8}$ in. wide by $1\frac{1}{4}$ in. thick strip. The stresses are fairly constant across the width except for a region about an inch wide on both edges of the strip. Presumably these edge variations would occupy a greater proportion of the width in narrower strips.[11]

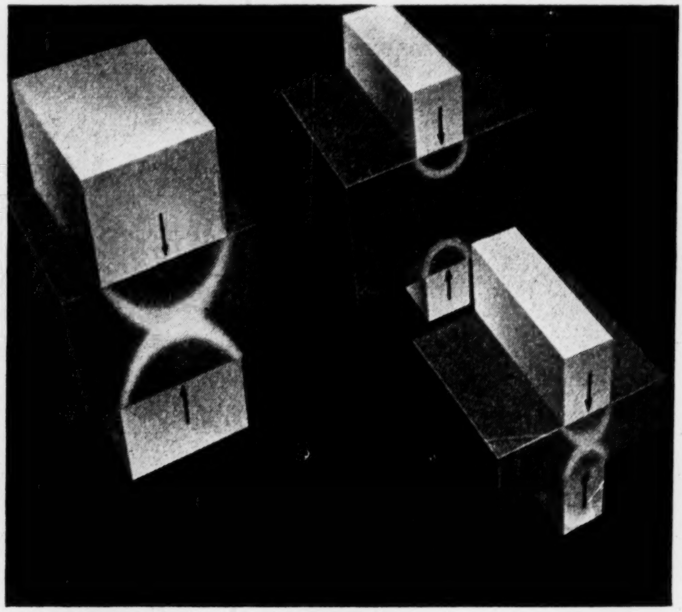

(*a*) (*b*) (*c*)

FIG. 33.—Regions in Which Plastic Flow is Initiated When Metal Blocks are Squeezed Between Flat-Faced Tools.

In (*b*) the ratio between the thickness of the metal and the width of the tool face is large. Plastic flow is initiated along a semi-circular region which extends to a relatively shallow portion of the block thickness. If the ratio between the thickness of the metal and the width of the tool face is reduced by either reducing the thickness of the metal block (*c*) or widening the tool face (*a*), the region in which plastic flow is initiated will extend throughout the thickness of the metal block.

The first type of residual stress pattern (Fig. 30(*a*)) has not been directly or experimentally observed, but is inferred from the analogous behavior of strip that is shot peened, or surface rolled (**29**), and from rod that is lightly drawn. It is presumed to arise in strip that is rolled extremely light amounts. Friedrich Körber (**30**) reviews the train of reasoning by which this residual stress pattern would be expected.

It is known, as Körber points out, that if a metal block is squeezed between two flat-faced tools plastic flow does not occur uniformly or simultaneously throughout the region between the tools. Instead flow will start in a restricted region which approximates a semi-circular cylinder having the flat face of the tool as a diameter (Fig. 32). As the tools are pressed into the block, plastic flow

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[10] Baker, Ricksecker, and Baldwin (**28**) state that "preliminary experiments showed that the residual stresses were uniaxial in the rolling direction" but the nature of their experiments provided a necessary, but not sufficient, proof that transverse stresses did not exist. Richards (**29**) reports transverse stresses in strip that is surface-rolled with a narrow-width roll.

[11] This trend would perhaps be accelerated by the greater freedom of narrow strips to spread laterally during rolling.

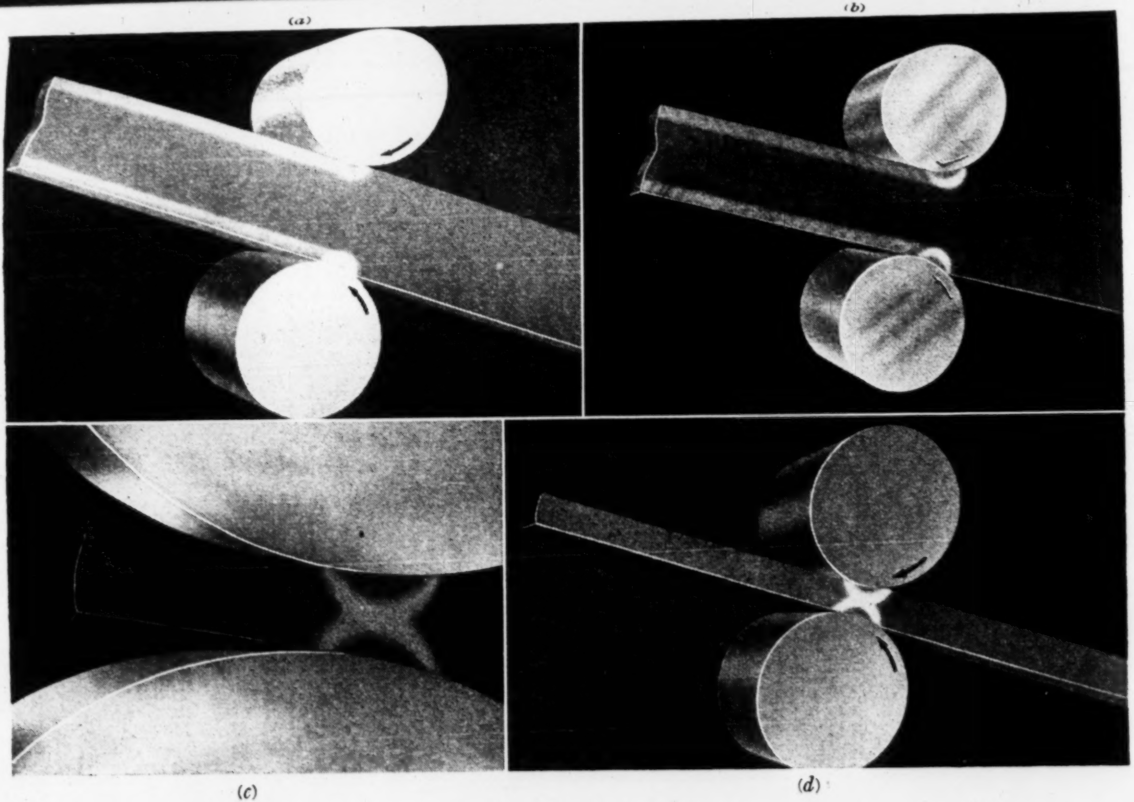


FIG. 34.—Strip Reduction.

In (*a*), a thick strip is being given a light reduction on small-diameter rolls. The ratio of strip thickness to contact length between roll and strip is thus large and plastic flow does not penetrate deeply into the metal strip. In (*b*), a heavier reduction is being made with the same rolls on the same strip. The ratio of strip thickness to contact length is reduced and plastic flow penetrates more deeply. In (*c*) the same strip is being given the same reduction as in (*b*), but this time with large-diameter rolls. The ratio of strip thickness to contact length is reduced substantially now and plastic flow penetrates the strip completely. In (*d*), a thin strip is given the same reduction as in (*b*), with the same size rolls. The ratio of strip thickness to contact length is again small and plastic flow penetrates the strip completely.

spreads out from this semi-circular region in a progressive fashion (Fig. 32). If the metal block is thick compared to the width of the tool face, the region in which plastic flow commences penetrates to a relatively shallow portion of the block thickness (Fig. 33(*b*)), whereas if the metal block is thin compared to the width of the tool face, the region in which plastic flow commences will course through the entire thickness of the block (Figs. 33(*a*) and (*c*)). These reactions have their counterpart in rolling: if the thickness of the strip being rolled is large compared to the length over which the roll contacts the metal strip, plastic flow will not penetrate the strip completely. It is readily seen that a small roll diameter, a light reduction in thickness, and a thick strip (all these factors being relative to each other) lead to non-penetrating conditions. Figure 34 shows a strip being rolled under these conditions. If the reduction in thickness is increased (strip thickness and roll diameter being held constant), the contact length between roll and strip is increased and plastic flow penetrates deeper (Fig. 34(*b*)). If the roll diameter is increased, the contact length is again increased and plastic flow penetrates still further (Fig. 34(*c*)). Alternately if the strip thickness is decreased, the contact length *relative to the strip thickness* is increased and flow again penetrates deeply (Fig. 34(*d*)). In the case of non-penetrating conditions (Figs. 34(*a*) and (*b*)), the surface layers of the strip would be cold worked and extended in length, the central layers would not. There will thus be a mutual reaction between these two areas, in which the inner

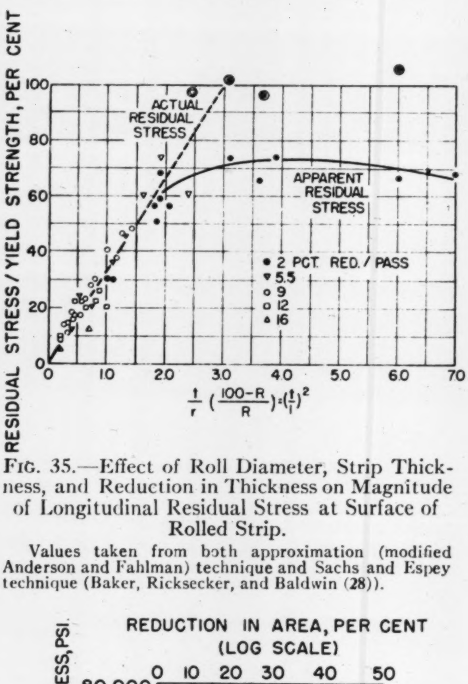
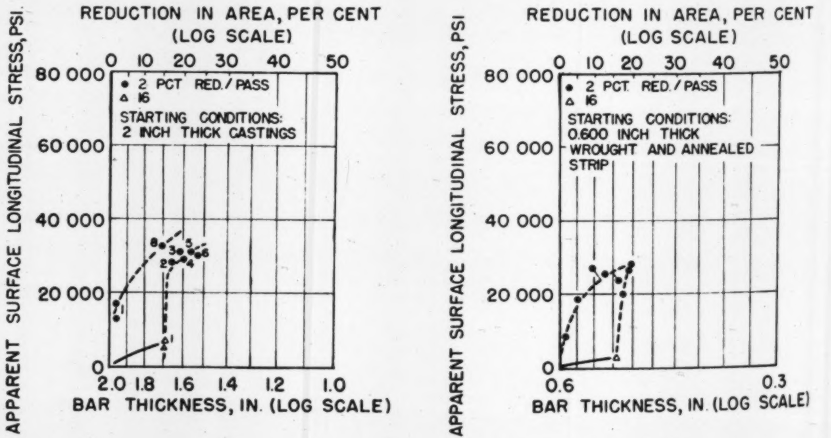


FIG. 35.—Effect of Roll Diameter, Strip Thickness, and Reduction in Thickness on Magnitude of Longitudinal Residual Stress at Surface of Rolled Strip.

Values taken from both approximation (modified Anderson and Fahlman) technique and Sachs and Espey technique (Baker, Ricksecker, and Baldwin (28)).

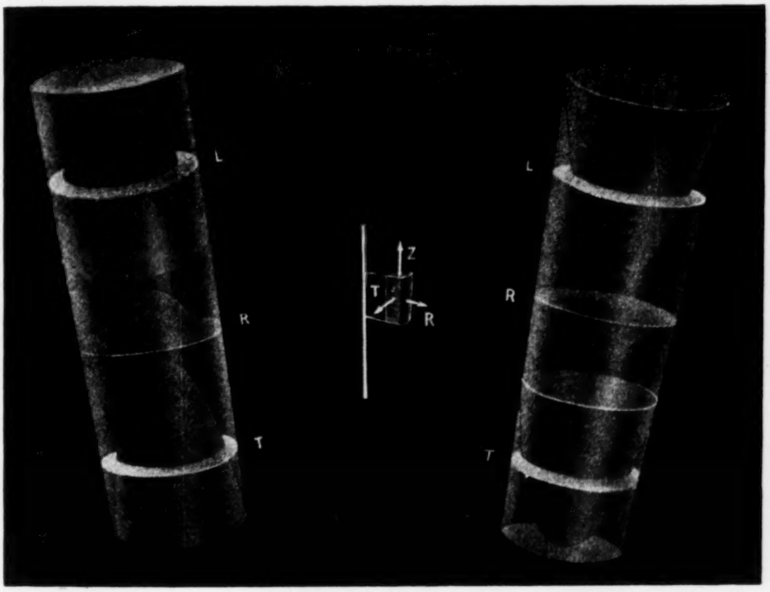


(*a*) (*b*)

FIG. 36.—Longitudinal Residual Stress at Surface of Rolled Strip as a Function of Rolling Schedule. Roll radius was 13 in. (Baker, Ricksecker, and Baldwin) Modified Anderson and Fahlman Technique.

layers seek to restrain the outer layers putting them in compression, and the outer layers seek to stretch the inner layers putting them in tension. It is in such a manner that the residual stress pattern of the first type, it is felt, is developed.

The second type of residual stress pattern has been experimentally observed—under rolling conditions in which plastic flow has penetrated the strip thickness (28). The actual magnitude of the stress at any point (let us say the rolling surface of the strip) will obviously depend upon factors inherent in the metal itself (for example, the elastic and plastic properties) yet quantitative data are available for only one alloy: an 88-per cent copper, 4-per cent lead, 4-per cent tin, 4-per cent zinc, bearing bronze (28).



(a) (b) (c)

FIG. 37.—Two Types of Residual Stress Patterns Found in Drawn Wire or Rod.

(b) Defines the directions in which longitudinal stresses, *L*, tangential stresses, *T*, and radial stresses, *R*, operate. In (a) and (c), three-dimensional charts illustrate how each of these stresses vary from point to point over a cross-section of the rod. In (a), for example, the graph shows the longitudinal stresses at the surface of the rod to be severely compressive (compressive stresses are indicated by points below the reference cross-section) rising to highly tensile values at the axis of the rod (tensile stresses are indicated by points above the reference cross-section.)

The magnitude of the stress at the rolling surface of the strip depends upon the geometric factors, roll diameter, strip thickness, and reduction in strip thickness: light reductions, relatively heavy strip thicknesses (or conversely relatively small roll diameters) give high residual stress patterns (Fig. 35). It appears, in fact, that the effects of these factors are such that the residual stresses are a function of the ratio of the strip thickness to the contact length between roll and strip —the same ratio which was of such importance in determining the residual stress pattern of the first type.[12]

No rationalization similar to that which attempts to explain the existance

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[12] In strip rolling with a succession of passes it appears further that the residual stress pattern is controlled largely by the last pass. Figures 36(*a*) and 36(*b*) illustrate how virtually the same (approximated) longitudinal residual stresses are developed in 4-4-4 bearing bronze strip either when rolled exclusively with 2 per cent reductions per pass or when rolled with a 16 per cent reduction per pass followed with a 2 per cent reduction per pass. Thus a final skin pass using a light reduction (to obtain close dimensional control, for example) can produce high residual stresses despite the fact that previous passes produced low residual stresses.

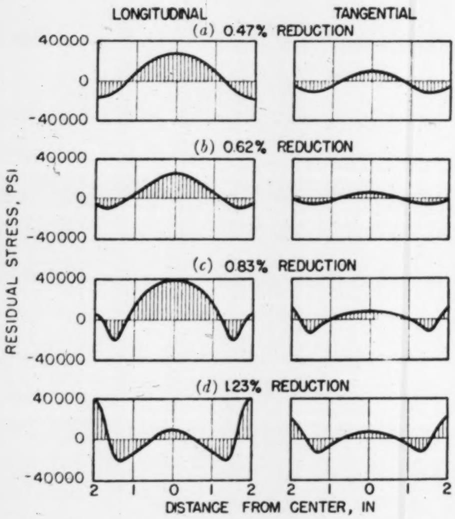

FIG. 38.—Longitudinal and Tangential Residual Stresses in Steel Rod Drawn Slight Amounts (Bühler and Buchholtz (**3**)) Mesnager-Sachs' Method.

of the residual stress pattern of the first type is available for the second residual stress pattern. In the light of the general principles by which the residual stresses may be prognosticated, we must await a complete analysis of the stresses existing in the strip during rolling. In the meantime, however, it may be noted that it is believed the roll pressures occurring during rolling may be closely approximated over a wide range of conditions by a function of the factor t/fl where t is the strip thickness, l is the contact length between roll and strip, and f is the coefficient of friction existing between roll and strip. This is of interest. The results of Baker, Ricksecker, and Baldwin, which were obtained on a single mill with a single alloy (under which conditions the coefficient of friction, f, would approach a constant value) indicate the dependence of residual stresses upon the ratio t/l. A more general investigation might reveal them to depend upon the ratio t/fl.

Drawn wire:

Drawn wire or rod is known to give two types of residual stress distribution.

In the stress distribution of the first type, longitudinal stresses are compressional in the outer hull of the rod and tensional in the core; radial stresses are tensional in the core and drop off (of necessity) to zero at the outer surface of the wire; hoop stresses are compressive in the core (Fig. 37(a)).

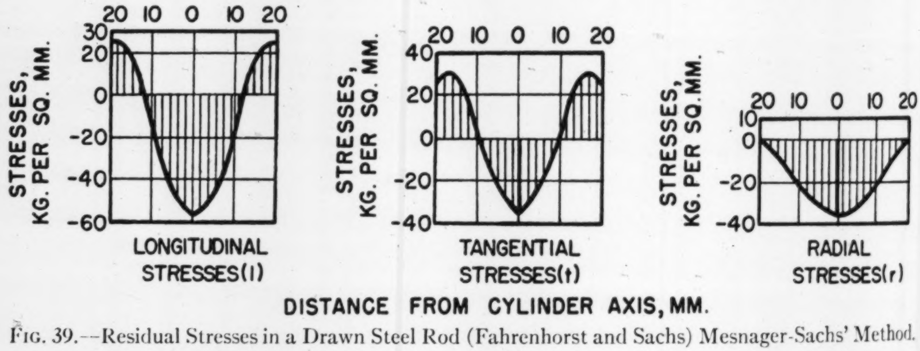

FIG. 39.—Residual Stresses in a Drawn Steel Rod (Fahrenhorst and Sachs) Mesnager-Sachs' Method.

The stress distribution of the second type is the exact reverse of the first type: longitudinal stresses are now tensile in the case, compressive in the core; radial stresses are compressive in the core dropping off to zero at the surface of the rod; hoop stresses are tensile at the surface of the wire and compressive at the wire axis.

It will be noticed that these two types of residual stress patterns duplicate the two types of patterns found in quenched rods, the first type of pattern corresponding to the contraction-type of quenching pattern, the second to the quenching pattern involving expansion.

The first type of pattern has been observed in steel rods that have been drawn very slight amounts (<1.0 per cent reduction in area) by Bühler and Buchholtz (**31**) (who used Sachs' boring out method) (Fig. 38(*a*)).

Naturally there are reductions in which transition patterns from the first to the second type of distribution have been observed (see Figs. 38(*b*) and (*d*)).

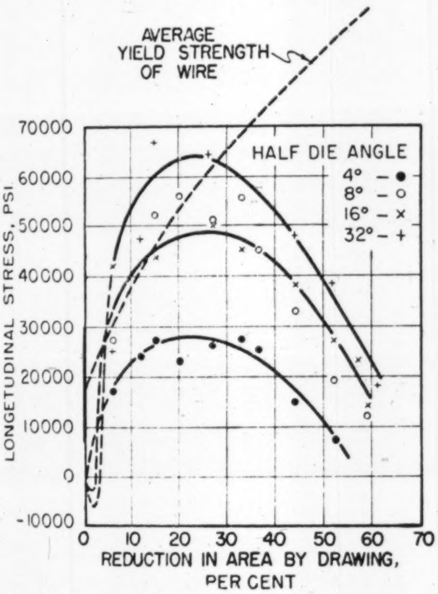

FIG. 40.—Approximated Longitudinal Residual Stress at the Surface of the Rod in Cold-Drawn Brass Wire, as a Function of Reduction in Area.

The reductions were made in a single pass (Linicus and Sachs (**33**) Modified Anderson-Fahlman Method.

In rationalizing their own findings, Bühler and Buchholtz (**31**) attribute the development of the residual stress pattern of the first type at low reductions in area to the non-penetration of work under these conditions. "If cold-working affects only the zones in the immediate neighborhood of the surface," they write, "then the plastically elongated surface zones on quitting the die will tend to lengthen the core of the rod which was only elastically loaded. The core will therefore be under tension, the outer hull in compression (in the longitudinal direction)." This reasoning, attractive as it is, will not account for the development of the radial or tangential stress distribution in the first type of pattern, however.

The presence of compressive hoop stresses in the outer hull of the rod indicates that the case is being restrained inward in the radial sense just as the presence of compressive longitudinal stress in the same zone indicates that the case is being shortened against its will. In other words, if the case could be parted from the core it would spring out from the core as well as lengthen. The similarlity between this residual stress pattern and the pattern resulting on transformationless quenching has already been noted. This type of pattern must result from either a triaxial contraction of the core relative to the case (as in the case of quenching) or a triaxial expansion of the case relative to the core.[13]

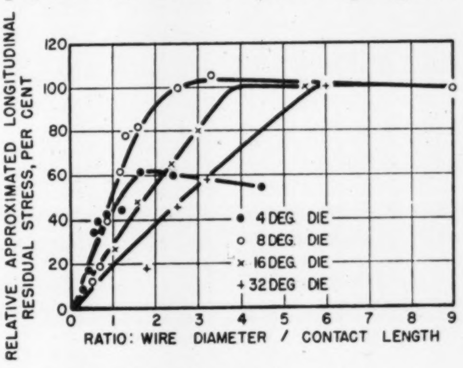

FIG. 41.—Data of Fig. 40 Transferred to the Same Type of Representation as Fig. 35.

There are no detailed investigations into the effects of die angle, frictional conditions, etc., on the first type of stress pattern. In the case of the second type it is apparent from Linicus and Sachs' (33) approximate data that the magnitude of longitudinal residual stress at the wire surface will be greater for a given single pass reduction, the greater the angle of the die (Fig. 40). These data also indicate that the magnitude of the longitudinal residual stress (for a given die angle) depends upon the reduction in area. In the absolute sense the (approximated) longitudinal residual stresses reach a maximum value at single-pass reductions in the range of 15 to 35 per cent, but in the relative sense, that is, when they are expressed as a fraction or percentage of the yield strength of the material, they fall continuously from a maximum value at the lightest reduction studied as the magnitude of the single-pass reduction is increased. As a matter of fact, if the (approximated) longitudinal residual stresses are expressed as a percentage of the yield strength of the wire as drawn and if they are plotted against the ratio of diameter of the drawn wire to the contact length between die and wire, a common trend curve of the type found for rolling results (Fig. 41). This can be regarded, however, as only the merest suggestion of a similarity in behavior between strip rolling and rod drawing.[14]

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[13] If it is found that compressive *transverse* residual stresses as well as compressive *longitudinal* residual stresses exist at the surface of strip rolled under nonpenetrating conditions, then Körber's explanation of the mechanism of the development of residual stresses under these conditions, similarly, is inadequate.

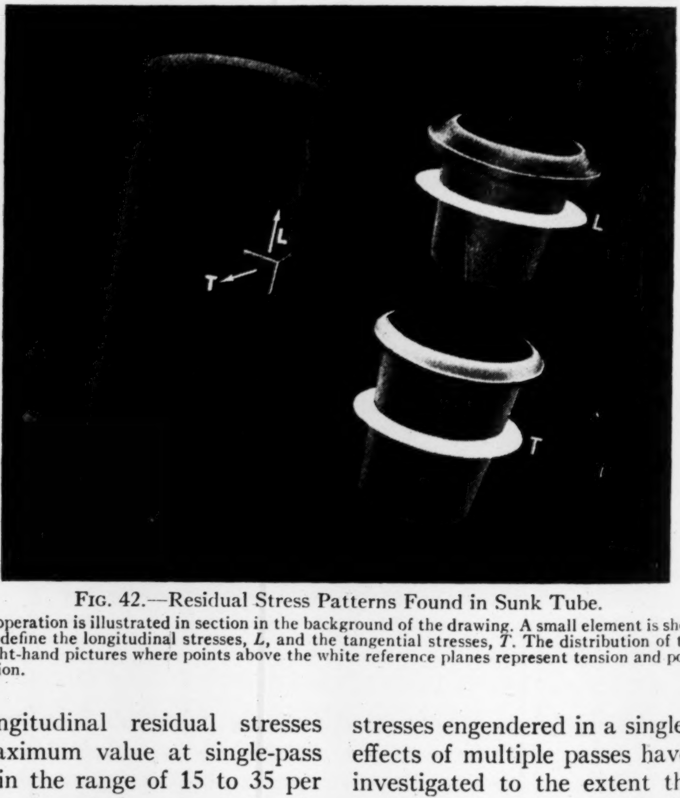

FIG. 42.—Residual Stress Patterns Found in Sunk Tube.

The sinking operation is illustrated in section in the background of the drawing. A small element is shown in the tube which serves to define the longitudinal stresses, *L*, and the tangential stresses, *T*. The distribution of these stresses is shown in the right-hand pictures where points above the white reference planes represent tension and points below represent compression.

All these data refer to the residual stresses engendered in a single pass. The effects of multiple passes have not been investigated to the extent that such a study seems justified. From the behavior of rolled strip it would be inferred that

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[14] The data are too approximate. The residual stresses as originally determined are only approximations. In addition the yield strength varies considerably over the cross-section in a drawn wire. The yield strengths used in computing the ordinates in Fig. 41 were average yield strengths of the drawn wire and not those at the surface of the wire (which were unknown). In addition the frictional conditions could have varied from die to die (note the erratic behavior of the 8-deg. die in Fig. 40), which factor as noted in the discussion under strip rolling undoubtedly enters into the picture.

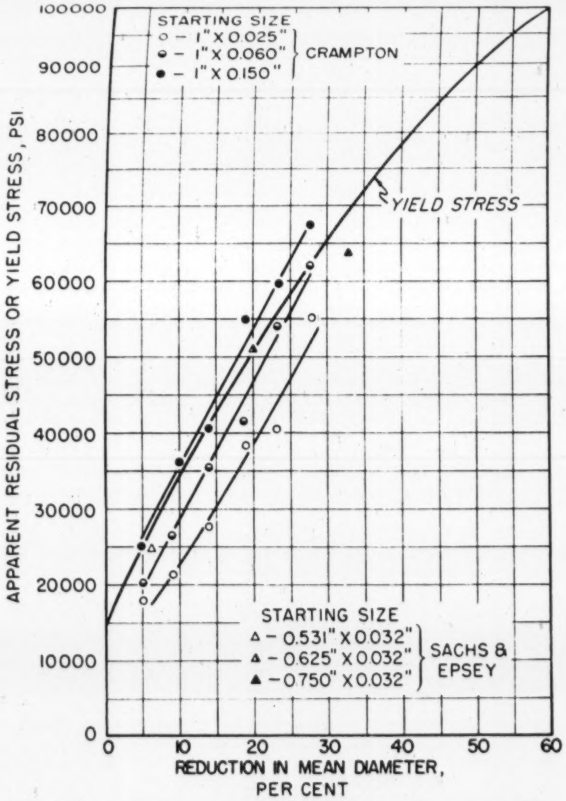


FIG. 43.—Approximated Residual Hoop Stress at Outer Surface of Sunk Tube as a Function of Reduction in Diameter. Reductions were effected in a single pass (Crampton (**15**)), Crampton Method.

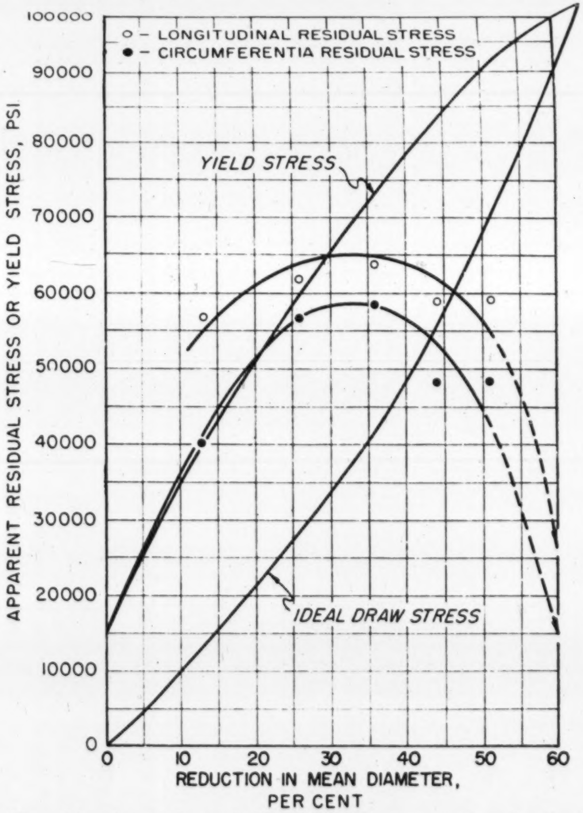
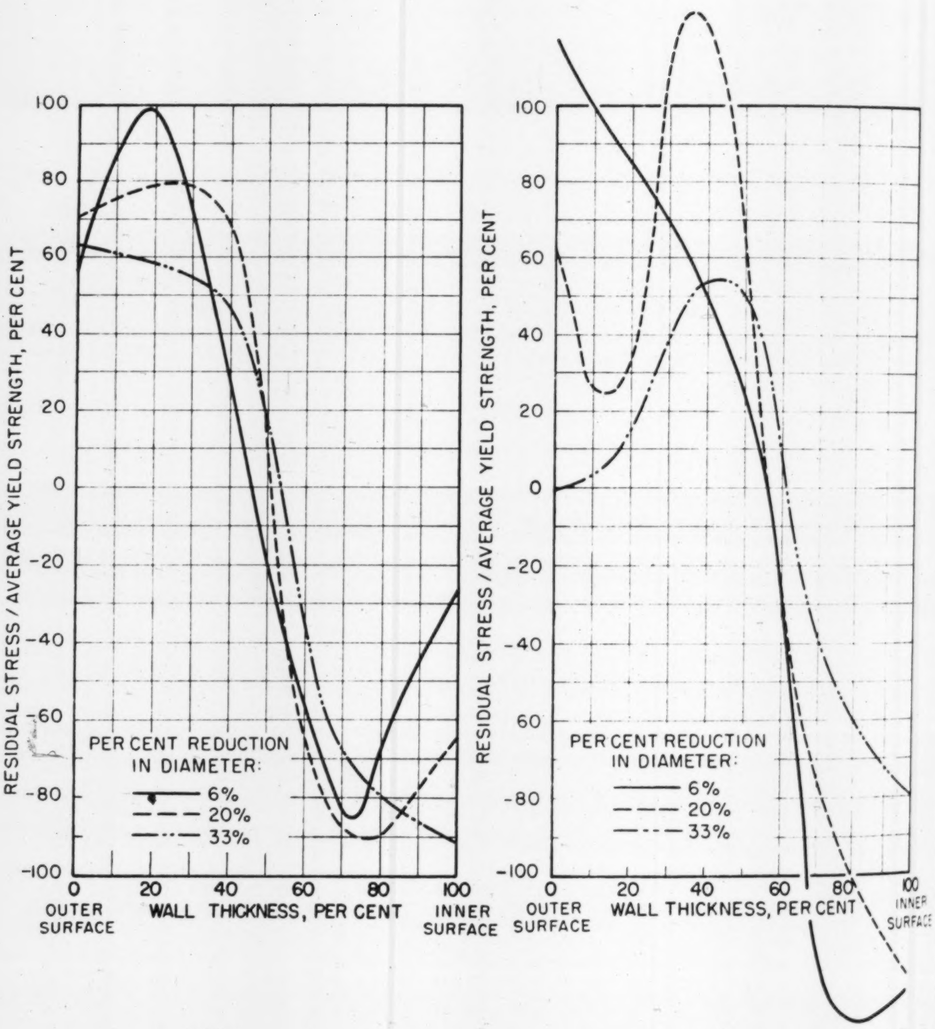


FIG. 44.—Approximated Residual Hoop and Longitudinal Stresses at Outer Surface of Sunk Tube as a Function of Reduction in Diameter. Reductions were effected in a single pass (Spear (**34**)) Crampton and Anderson-Fahlman Deflection Methods.



(*a*) (*b*)

FIG. 45.—Actual Distribution of Residual Stresses Tthroughout Wall of Sunk Tube (*a*) Tangential Stress and (*b*) Longitudinal Stress. (Sachs and Espey (**12**)). Sachs and Espey Technique.

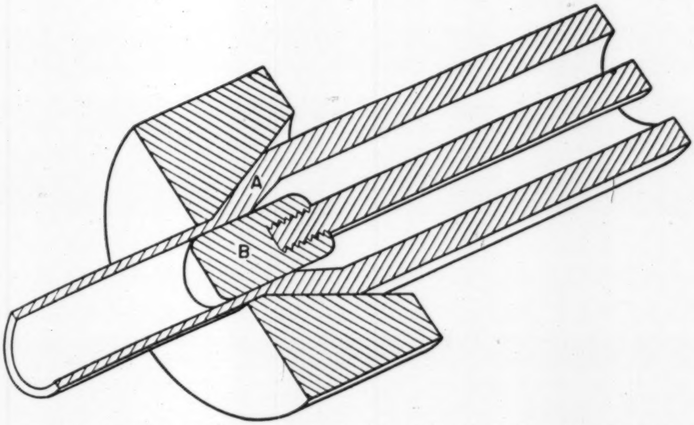


FIG. 46.—Diagrammatic Representation of the Tube Drawing Operation.

Tube drawing is actually a compound operation in which the tube diameter is first reduced or sunk (region *A*) after which the tube wall is thinned by the internal plug (region *B*). Practical considerations (dimensional control, surface quality of inner wall, etc.) make this sequence almost universal.

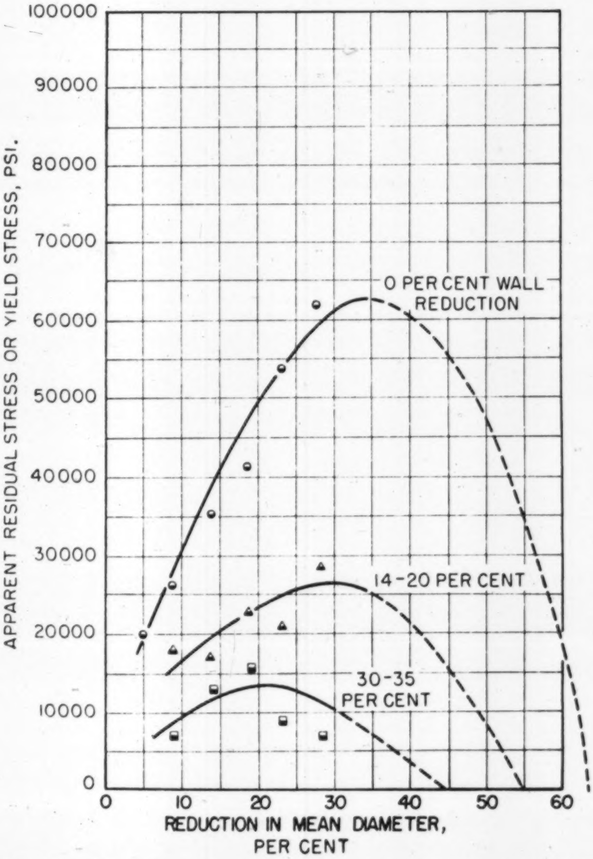


FIG. 47.—Approximated Residual Hoop Stresses at Outer Wall Surface of Drawn High Brass Tube. Reductions were made in a single pass (Crampton (15)) Crampton Deflection Method.

the residual stresses developed by a multiple pass drawing schedule would be largely determined by the last single pass.

Sunk Tube:

Tube sinking is that process by which a tube is drawn through a die without a plug or mandrel to support the internal wall. Undoubtedly tube sinking can develop two types of residual stress patterns just as strip rolling and wire drawing do: one type that is associated with non-penetrating work and the other associated with penetrating work. The conditions leading to non-penetrating work have never been studied, however, and the only residual stress patterns reported are those resulting from sinking conditions that must have produced penetrating work. These are represented in Fig. 42. The residual stresses acting in the direction of the tube axis are tensile in the outer half of the wall and compressive in the inner half; those acting in the hoop direction follow the same course. The radial stresses must of necessity be zero at the inner and outer wall of the tube and, in thin-walled tube at least, probably never assume very high values.[15]

Crampton's approximate data (**15**) show that the magnitude of the hoop stress at the outer tube surface increases with increasing reduction in diameter, almost duplicating the value of the yield strength of the alloy he studied (Fig. 43).[16] If an analogous behavior between wire drawing and tube sinking exists, this trend would not be expected to continue at higher reductions. Exploratory tests by Spear (**34**) confirm this (Fig. 44). Sachs and Espey (**12**) have reported the actual stress distributions for the tube sunk to three different reductions. The circumferential residual stresses are fairly simple in their distribution (Fig. 45); the longitudinal stresses show a sharp maximum about a quarter of the way in from the outer surface. Whether this maximum is caused by bending action which the tube wall suffers as it quits the die (compare Fig. 4) is difficult to say.

Drawn Tube:

Tube drawing, in which a plug or mandrel works against the inner wall of a tube that is being drawn through a die, is a compound operation. The tube is first reduced in diameter (sinking) and then reduced in wall thickness (Fig. 46). No data on the exact distribution of residual stresses in drawn tube have been reported, but from approximate data it appears that the stress distributions must be approximately of the same general type as that found in tube sinking. The process would be expected to be capable of producing considerable variation in the stress distributions, however, since the reduction of the wall—a process akin to strip drawing or rolling—may be expected to alter the residual stresses that the preliminary sink might otherwise impress upon the tube. From the behavior of rolled strip it would be anticipated that the smaller the ratio of wall thickness to contact length over which thinning of the wall is being effected, the lower will be the residual stress produced. These expectations are borne out by Crampton's approximate data for tube drawing (Fig. 47).[17]

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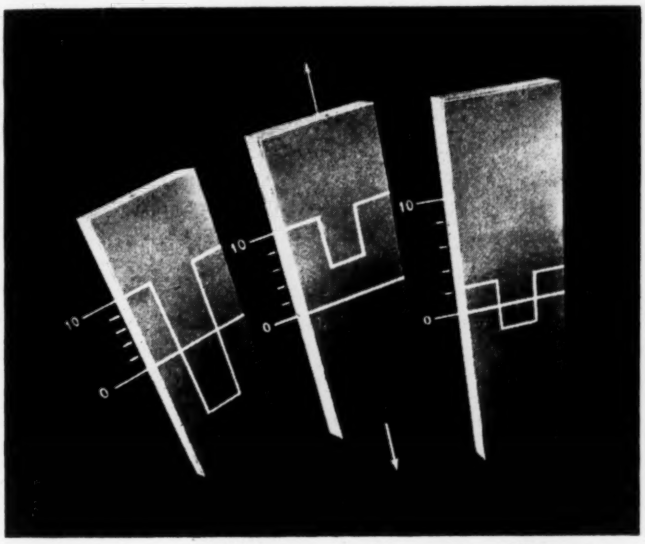
[15] Pure cupping operations (where no ironing of the cup wall occurs) are similar to sinking operation and develop similar residual stress patterns.

[16] Since both the longitudinal and hoop stress are tensile in the outer half of the wall and compressive in the inner half (the radial stresses being negligible), the limiting value for the residual stresses in the first approximation will be the yield strength of the alloy as determined in simple tension.

[17] Compound cupping operations (where ironing of the cup wall is effected) and mandrel redraw operations are similar to tube drawing and develop similar residual stress patterns.

RELIEF OF RESIDUAL STRESSES

Since, as we have seen, residual stresses are to be found in metals produced under a wide variety of processes, and since as we shall see, residual stresses can be quite detrimental under certain service conditions, there is a natural interest in methods by which residual stresses can be annulled or at least reduced in intensity.



(*a*) (*b*) (*c*)

FIG. 48.—The Action of Stretching on Residual Stresses Operating in the Direction of Stretching.

Annulment of Residual Stresses by Heating:

Residual stresses may be reduced by heating the afflicted metal. "Relief annealing" is the usual term applied to such a process, but in a strict sense it lays exclusive emphasis on the rôle of heat in the dissipation of the stress state. It might lead the unwary to the belief that the reduction of stress is a function of temperature alone, that to each temperature there corresponds a reduced residual stress state instantaneously achieved. It is true that the strained condition of the metal is eventually restored to its strain-free condition by the thermal agitation of the atoms about their mean sites in the crystal structure. But the movement of atoms from strained positions to unstrained positions is not an instantaneous cataclysm, for it is highly improbable that the complex but organized thermal vibration pattern should be exactly that which would immediately drop all atoms into their unstrained positions. Rather—on the basis of probability still—it is a time-consuming process by which individual atoms move from a strained mean site to a locally metastable position (which position, as subsequent atoms reassemble themselves, becomes highly unstable or strained) through various stages to a position which is ultimately compatible with gross areas—that is, grossly strain-free. At all temperatures save absolute zero this process occurs, *but it takes time.* Residual stresses will slowly decompose at room temperature. The rôle of temperature is to increase the number and frequency of thermal vibrations, to increase the probability of passage from strained to unstrained states, to increase the rate at which stresses are relieved.

Annulment of Residual Stresses by Cold Working:

The residual stress pattern contained in a metal may be altered by subjecting the metal to plastic deformation. A simple example is illustrated in Fig. 48 (*a*) (35). A metal strip may be presumed to possess tensile residual stresses equal to the yield strength in its outer layers and compressive residual stresses equal to the yield strength in its central layers. If now, the metal is stretched, the metal in the outer layers will immediately flow plastically, the stress increasing slowly in this region according to the degree of work hardening that the metal evidences. The metal in the central layers elastically deforms, the stress increasing rapidly according to Hooke's law. If now the stretching is relaxed, the stresses subside uniformly across the width of the specimen to give the residual stress pattern shown in Fig. 48(*c*). It is apparent that stretching has materially altered (in this case reduced) the original residual stress pattern.

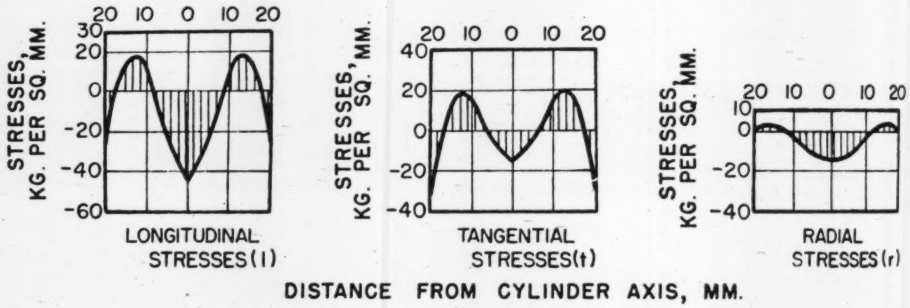


FIG. 49.—Residual Stress Distribution in a Steel Rod Cold-Drawn and then Surface-Rolled. Compare with Fig. 39 (Fahrenhorst and Sachs (**32**)) Mesnager-Sachs Method.

It would be a mistake to convey the opinion that all forms of cold work *reduce* originally existent residual stress patterns. In general any cold working tends to produce the same residual stress pattern whether a stress pattern existed in the original stock or not. As we have seen, (Fig. 36) some cold working processes produce high residual stress patterns.

Some of these high residual stress patterns are beneficial in themselves or are beneficial in that they can be used to annul malignant stress patterns. In the section "Effects of Residual Stresses" it will be seen that the presence of residual tensile stresses at the *surface* of metallic shapes is, in general, deleterious and the reduction of such stresses or the conversion of such stresses to compressive stresses is thus advantageous and in some cases mandatory. As a generalization, therefore, it can be stated that any of the surface working processes (surface rolling, surface drawing, shot peening, etc.) can be employed as residual stress "relief" measures since they tend to induce compressive residual stresses at the metallic surface. Repeated bending can be similarly employed.

A common practical application of these principles is the use of skew-roll straightening (which is a surface-rolling operation) in reducing deleterious residual stress states in drawn rod or wire (Fig. 49).

EFFECTS OF RESIDUAL STRESSES

Residual Stresses and Distortion:

We have already noted that residual stresses occur as the result of a mismatch in various regions of a metal and that segmenting a metal part will cause the mismatch to become evident. It comes as no surprise to learn, then, that a residually stressed metal can warp or distort when machined or cut. The obvious curling of planed plates, or snaking of threaded rods is readily attributed by the engineer to residual stresses. There are a number of less obvious ways in which residual stresses can work evil and because they are not readily recognized they are more insidious. Drilling radial holes into drawn rods, for example, releases residual stresses such that the hole changes in diameter slightly (as in Mather's local strain technique of determining residual stresses (16)). These slight changes in hole size, while not affecting rough drilling operations, can cause critical finishing operations to break down (due to binding of drills or reamers, etc.). The rod is usually blamed for being poor in "machinability."

Residual stresses sometimes play an intermediate rôle between ultimate cause and effect in some warping problems and are overlooked. When rolled strip is slit and cambers, it usually is recognized that the strip was hump-rolled, that is, rolled such that the center of the strip (with reference to its width) received a greater reduction than the edges. The fact that the retained elastic (residual) stresses are the only active agent in causing the camber is frequently overlooked. If such stresses are relieved by suitable means (relief annealing) cambering would not occur.

Residual Stresses and Fracture:

Residual stresses are an important contributing factor in the fracturing of metals and other substances.

Timoshenko (2) discusses the case of a residually stressed brittle body that is parted. The residual stress state may be so disturbed as to produce stresses exceeding the fracture stress and cause failure. The particular example Timoshenko describes is that of a glass ring having a residual stress distribution of the nature shown in Fig. 50. Timoshenko goes on to suggest that such a general mechanism could easily account for the cracks that occur on occasion when glass is cut.

Certainly another case of this type is the explosive failure of Prince Rupert drops. These drops you will recall are quenched tear-shaped glass droplets loaded with residual stresses. Removing the tip of the tear drop by suitable means causes the remainder of the drop to explode.

It must be concluded, that residual stresses are a potent medium for propagating brittle failure if the residual stress state is critically disturbed. In the examples cited so far the disturbance resulted from the mechanical removal of part of, or the severence of the body, but this disturbance quite possibly could be effected by other means.

Many metals in the presence of certain corroding media will develop cracks. If, in addition, the metal is stressed this type

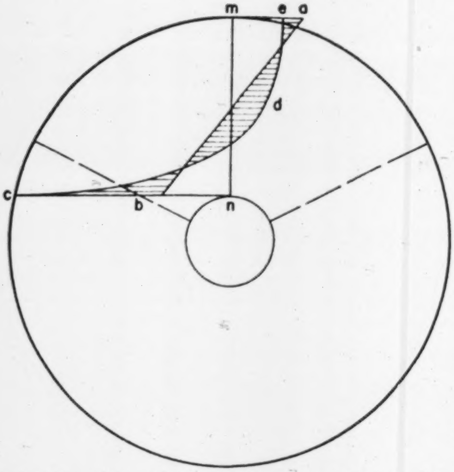


FIG. 50.—Timoshenko's Example of how Residual Stresses may Cause Fracture in Brittle Substances.

A glass ring is presumed to contain tangential residual stress distributed along the cross-section *mn* according to the line *ab*. If the ring be cut radially along the dashed lines, the residual stresses cause the ring to spring inward. Such an elastic deformation would normally be accomplished by the application to the ends of each portion of the ring of two equal and opposite couples, the action of which would be opposed by the internal stress distribution *cde*. In the present case, the residual stress in the glass ring after cutting will be the difference between *ab* and *cde* as shown in the figure by the shaded area. If the inner radius of the ring is small, there is a high stress concentration at the inner boundary, and the maximum residual stress after inner cutting represented by *bc* may be larger than the maximum stress before cutting.

of attack will be enormously accelerated even to the point of explosive violence. Cracking of iron or steel when exposed to hot caustic solutions or copper alloys when exposed to ammoniacal solutions or silver alloys to ferric chloride solutions and of aluminum, magnesium and even gold alloys to other corrosive media have been extensively discussed in the literature (**36**). The exact nature by which such rapid failures occur is certainly not known. Empirically it has been observed that the fractures are brittle, showing no localized deformation near the crack, that the cracks develop catastrophically rather than gradually, that a given metal will react to only certain select corroding media, that the composition of the alloy is critical, and that the time required for such failures to occur is tremendously reduced as stress is increased. A closely related phenomenon is the cracking of metals when stressed in the presence of molten metals or alloys. Steels will crack when exposed to molten tin, antimony, white metal, aluminum, copper, etc.; copper alloys, though immune when stress-

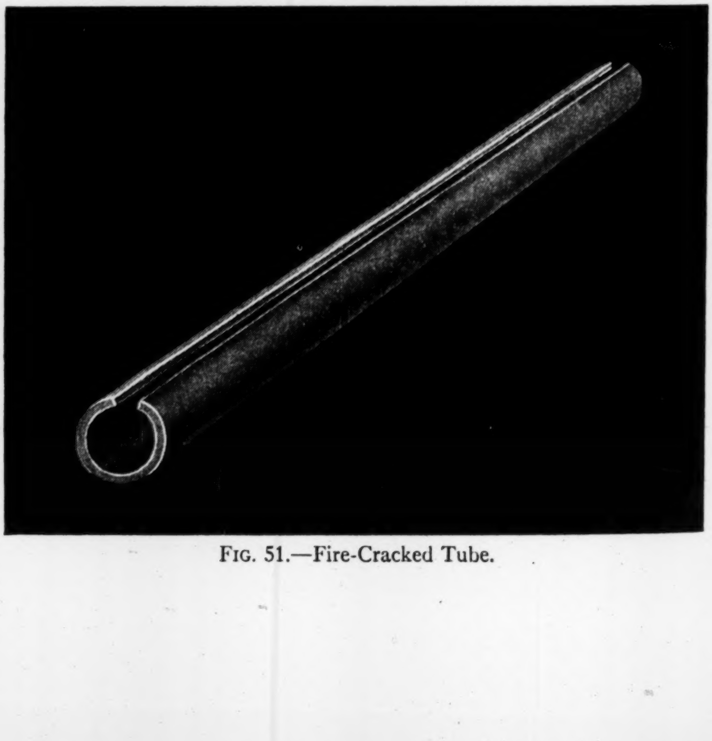


FIG. 51.—Fire-Cracked Tube.

free, will crack when stressed if exposed to lead, tin, solder, mercury (at room temperature); aluminum can crack in contact with aluminum solders. As in the case of stress-corrosion cracking in aqueous solutions, the failures are brittle, there is a selectivity between metal and corroding medium, the composition of the alloy is critical, and high stress will reduce the cracking time enormously. The qualitative relation between stress and time, for example, is exploited in the mercurous nitrate test—as described in A.S.T.M. Method B 154 - 45[18]—as a quick means of determining the presence of residual stresses. The explosive failures that occasionally occur in the course of this test are suggestive of the failures discussed in the case of Timoshenko's glass ring and Prince Rupert's drops, and raise the speculative question of whether the action of mercury is a dual one of embrittling the metal and critically disturbing the residual stress state.

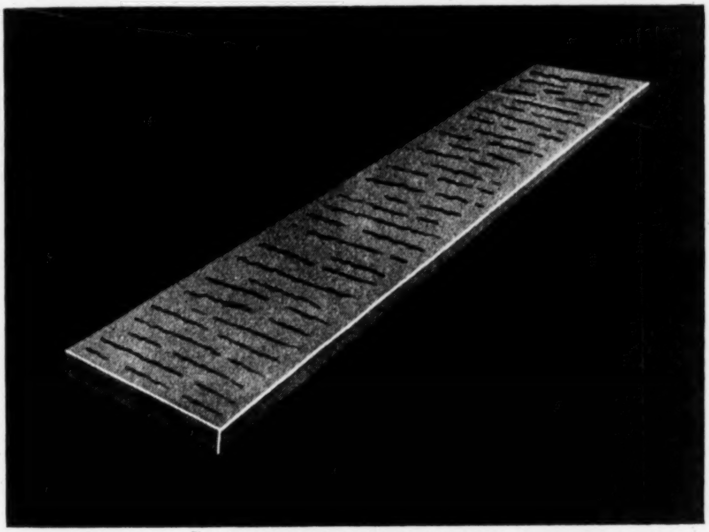


FIG. 52.—Fire-Cracked Strip.

Stressed metals when heated can crack. It should be recalled that while heat can relieve residual stresses, the process is not instantaneous and that consequently residual stresses can operate in metals for finite times. The effects of residual stresses can be made more virulent by the added action of thermal stresses when heating is sudden or rapid. The simplest explanation for such cracking is that residual stresses (in conjunction with thermal stresses) exceed the fracture stress of the metal (which falls with rising temperature) and failure ensues. Such a simple explanation misses, however, some of the subtleties involved in the various modes of failure to the extent that the measures proposed for the avoidance of one type of heat cracking can aggravate another type of heat cracking. One type of heat cracking is commonly termed fire-cracking. It is characterized by gross failures extending the length of a tube (Fig. 51), across the width of a sheet (Fig. 52), or as a maze of cracks on a strip surface. The failures are brittle. They occur catastrophically. The presence of certain low-melting impurities (such as lead or tin in copper alloys) greatly increases the susceptibility of an alloy to fire-cracking. Because of these facts, there is legitimate reason to speculate as to whether this is not a specialized case of cracking in the presence of liquid metals, the liquid metal in this case being accessible within the metal itself instead of diffusing into the metal from an exterior medium. In contrast, were the failure to be purely mechanical, some ductility should be in evidence and the failures should be confined to relatively localized zones. Definitive experiments would be most helpful here. To eliminate fire-cracking, low-melting impurities should be avoided (in the event that they are not intentionally added constituents of the alloy), the stress state may be avoided in the original work, or a low heating rate may be employed both to effect relief of the residual stress state before reaching the working temperature and to minimize thermal stresses.

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[18] Standard Method of Mercurous Nitrate Test for Copper and Copper Alloys, 1946 Book of A.S.T.M. Standards, Part I-B, p. 134.

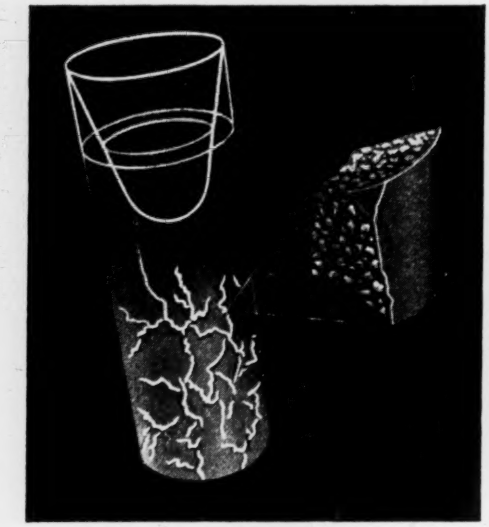

FIG. 53.—Cracks Formed in Rod when Age-Hardened in the As-Drawn Condition.

The section to the left depicts the distribution of both longitudinal and tangential residual stresses in a drawn rod It is to be noticed that both of these stresses are tensile in the surface of the rod. This stress field together with the stresses resulting from the precipitation of a second phase can cause cracking as shown in the right-hand drawing.

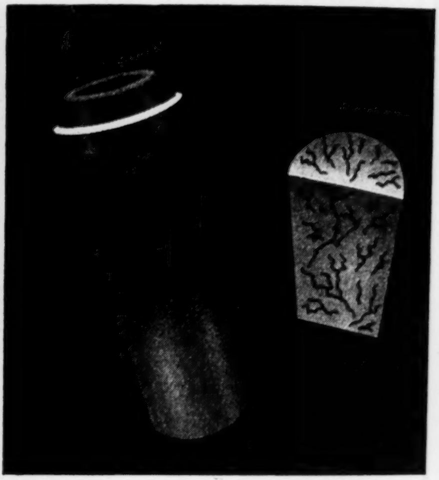

FIG. 54.—Stress Precipitation Cracking Occurring in Insufficiently Skew-Rolled Rod.

Tensile stresses may be reduced sufficiently at the surface of the rod but not at some point in the interior. Cracks occur then beneath the surface where they are difficult to detect.

Still another failure that occurs on heating a stressed metal to elevated temperature is precipitation stress-cracking. Although the effects of this phenomenon are similar to, and are often confused with, those of fire-cracking, there are important differences between it and fire-cracking, both in mechanism and, from the practical side, countermeasures for its avoidance.

We have already stated that precipitations occurring with volume change within alloys will create stress fields in both the precipitate and the enveloping matrix. Although the modes of precipitation are myriad, a common habit of precipitates is to be lain down in dense mist-like sheets at grain boundaries, slip planes, twin boundaries, etc. Such concentrated and oriented precipitation fields engender coherent and directed stress fields. Augmented by a coherent and directed gross or pervading residual stress field—resulting from plastic working, for example—the precipitation stresses can rupture the metal. The fabrication of some age-hardening alloys thus requires astute and judicious control. Aging rods or wires as drawn, in which condition as we have seen, the outer hull is biaxially stressed in tension (in the longitudinal and circumferential directions), will create jagged brittle fractures of the type shown in Fig. 53. Removal of the gross stress field resulting from drawing can reduce the level of stress induced by precipitation alone to a point where cracks are not developed on aging. The method of removal of the gross stress field poses problems, however. Thermal methods (stress relief annealing) would cause precipitation and cracking. (It is in this respect that precipitation stress cracking can be distinguished from fire-cracking: In the latter case a slow heating rate suffices to cause relief of residual stress and thus eliminate failure.) Mechanical methods thus represent the most practical solution. Surface rolling of regular shapes, (sheets, rods, or tubes, etc.), or shot peening of irregular shapes will reduce dangerously high tensile stress fields or convert them to salutory compressive stress fields. Such cracks as shown in Fig. 53 can be completely prevented by surface rolling (skew-roller straightening). Even here it cannot be assumed that *all* surface rolling will eliminate the development of cracks and due cognizance of the fact must be taken that the reduction of tensile residual stresses is not a cataclysmic reaction that occurs suddenly at the magic touch of a straightening machine, but rather is a gradual transition depending, as we have seen, upon certain geometric and mechanical variables. Insufficient surface rolling will partially relieve crack formation in an insidious way. Figure 54 is a view of a drawn rod straightened insufficiently prior to aging. The straightening has converted the surface stresses from tensile to compressive and prevented cracking there, but its effects have not penetrated deep enough to annul enough of the tensile stress produced during drawing to prevent cracking below the surface where it cannot be found by superficial inspection but where it can play havoc in subsequent machining operations, fatigue performance, etc.

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EFFECT OF MANUFACTURING PRACTICE ON CREEP AND CREEP-RUPTURE STRENGTH OF LOW-CARBON STEEL*

By G. V. Smith[1] and E. J. Dulis[1]

Synopsis

Comparative creep to rupture tests at 850 F. on twelve heats of low-carbon steel made by different melting and deoxidation practices show a rather wide range in results dependent chiefly upon the deoxidation practice employed.

Examination of published data on the creep strength of low-carbon steel at any given temperature reveals a wide spread in stress required to produce a given creep rate. Since it has been established that the reproducibility of creep tests in different laboratories may be of a high order (**1**),[2] it seems probable that this wide spread in results is to be attributed largely to differences in deoxidation and other manufacturing practices as well as to differences in heat treatment. This has been recognized for some time, and in an effort to evaluate the influence of such variables, the Joint A.S.M.E.-A.S.T.M. Research Committee on the Effect of Temperature on the Properties of Metals has sponsored a program of experimental research. The results of this investigation, which has involved comparative creep tests of relatively short duration and which is still under way, have been presented in a series of progress reports (**2**, **3**, **4**). They clearly show that deoxidation practice, heat treatment temperature, and mode of cooling therefrom exert a very significant influence on creep strength. For carbon steels of similar heat treatment, the results indicate a detrimental effect of large aluminum addition for deoxidation, although a moderate amount of this deoxidant added with silicon yielded a steel slightly more creep-resistant than one deoxidized with silicon only.

More recently, Glen (**5**) has reported on the "abnormal" creep of carbon steels, by which is meant "a deterioration in creep characteristics due to deoxidation practice, involving differences in the amounts of aluminum and silicon used," and of ameliorating the effect by adding manganese, silicon, and molybdenum. Glen observed, however, that aluminum resulted in "appreciable" deterioration only when the addition was sufficiently large to yield a fine grain size in the usual carburizing grain-size test.

The present paper presents the results of creep and creep-to-rupture tests at 850 F. for periods up to 3500 hr. on 12 heats of normalized low-carbon steel of commercial manufacture, representing various refining and deoxidation practices.

Material and Procedure

The identification, type of steel, chemical analysis, and deoxidation practice of twelve steels investigated are given in Table I. Capped steels A and B represent the one extreme of steels essentially not deoxidized, whereas the remainder represent different degreees and types of deoxidation. Both open-hearth and bessemer steels are included. Steels E, F, G, and H are open-hearth steels deoxidized with silicon or silicon aluminum. The last four steels, I, J, K, and L, represent killed bessemer steel and are unusual in that prior to final ladle deoxidation they are recarburized and partially deoxidized in the converter by the addition of molten pig iron.

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 599.

Steels A, B, F, H, I, J, and L were received in the form of longitudinal slices of pipe of ¾-in. wall thickness, whereas the remainder were received as 1-in. diameter rolled bar. Prior to machining into test specimens, all of the steels were heated at 1650 F. for ½ hr. and air-cooled (normalized). The resulting A.S.T.M. ferrite grain size ranged from 3 to 9 and the Vickers hardness from 90 to 145; both are listed in Table II. The microstructure of steel E, which is representative of all except the two higher carbon steels, F and H, is shown in Fig. 1(*a*). The microstructure of steel H, representative of the two higher carbon steels, is shown in Fig. 2(*a*).

TABLE I.—DESCRIPTION OF STEELS.

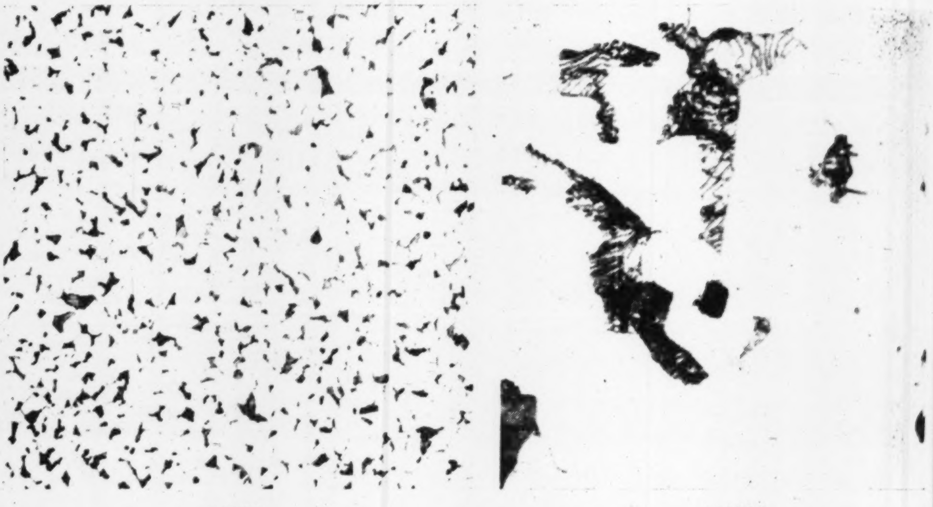
Code	Heat	Type	Check Analysis, per cent[a]									Main Deoxidizers,[b] lb. per ton
			C	Mn	P	S	Si	Al	Al_2O_3	N	Ti	
A....	No. 9188	Capped open-hearth	0.07	0.45	0.006	0.020	0.005	...	...	0.004	...	None
B....	No. 22432	Capped bessemer	0.08	0.38	0.079	0.037	0.005	...	...	0.013	...	None
C....	No. 2261	Si-Ti killed open-hearth	0.19	0.47	0.009	0.028	0.18	0.005	0.002	0.006	0.002	10 FeSi, 6 FeCTi
D....	No. 7250	Si-Al-Ti killed open-hearth	0.16	0.48	0.008	0.022	0.20	0.004	0.002	0.005	0.003	10 FeSi, 4 FeCTi, 0.5 Al
E....	No. 2257	Si-Al killed open-hearth	0.15	0.47	0.011	0.023	0.19	0.007	0.003	0.006	0.001	10 FeSi, 1 Al
F....	No. 11019	Si-Al killed open-hearth	0.24	0.86	0.013	0.021	0.23	0.033	...	0.009	...	8.4 FeSi, 1.8 Al
G....	No. 25424	Si-Al killed open-hearth	0.16	0.51	0.013	0.020	0.16	0.035	0.006	0.009	...	7 FeSi, 2 Al
H....	No. 10200	Si killed open-hearth	0.27	0.52	0.016	0.025	0.22	0.006	...	0.006	...	7.7 FeSi
I....	No. 22770	Si-Al killed bessemer	0.14	0.54	0.074	0.022	0.18	0.025	...	0.013	...	6.8 FeSi, 3.4 Al
J....	No. 9934	Si-Al killed bessemer	0.13	0.48	0.087	0.029	0.21	0.047	...	0.020	...	10 FeSi, 3 Al
K....	No. 4345	Si-Al killed bessemer	0.15	0.46	0.088	0.018	0.22	0.024	0.005	0.022	...	10 FeSi, 2.5 Al
L....	No. 22773	Al killed bessemer	0.18	0.51	0.077	0.022	0.03	0.066	...	0.020	...	3.4 Al

[a] The absence of a value indicates that no determination was made.

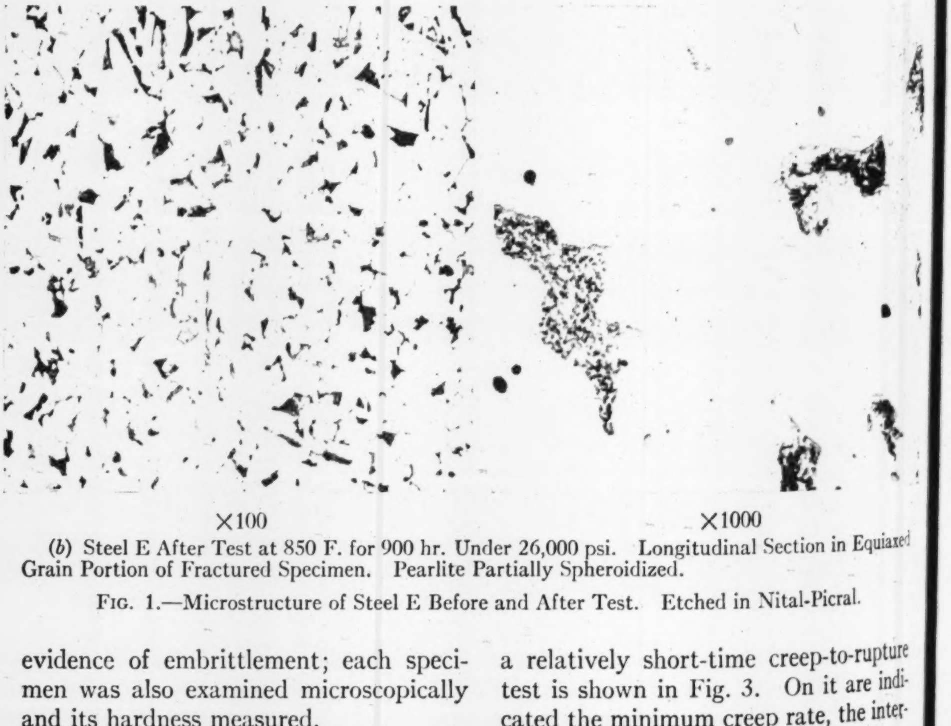
[b] FeSi refers to ferro-silicon; FeCTi refers to ferro-carbon-titanium; Al, to aluminum.

The creep and creep-to-rupture tests were made at 850 F. employing the equipment and procedures which have been described earlier (6). As described therein, tension-type specimens ¼ in. in diameter by 1-in. gage length are employed for the creep-to-rupture tests, while ½-in. diameter by 2-in. gage length specimens are employed for the creep tests not continued to fracture. In the latter tests, the creep of the specimen is determined directly by sighting with a microscope, through a window in the heating furnace, upon reference units rigidly attached to the specimen. The considerably larger creep of the creep-to-rupture test specimens is recorded autographically from the deflection of the loading lever. The initial deflection on loading is in error when measured in such a way owing to the deflection of the test stand itself; this deflection in the test stand is proportional to the load and hence a correction may be applied to the measured deflection to give a good approximation of the initial extension of the specimen. During test, only the reduced section of the test specimen deforms, since the load remains constant, and accordingly the lever deflection is an accurate measure of the creep of the test specimen.

After test, the specimens which had fractured were examined microscopically for evidence as to the nature of the fracture and for evidence of microstructural changes. Notch impact specimens ($\frac{2}{3}$ size) were machined from test specimens discontinued before fracture and tested at room temperature for evidence of embrittlement; each specimen was also examined microscopically and its hardness measured.



(*a*) Steel E Before Test, Transverse Section, Ferritic Matrix with Well Defined Pearlite.

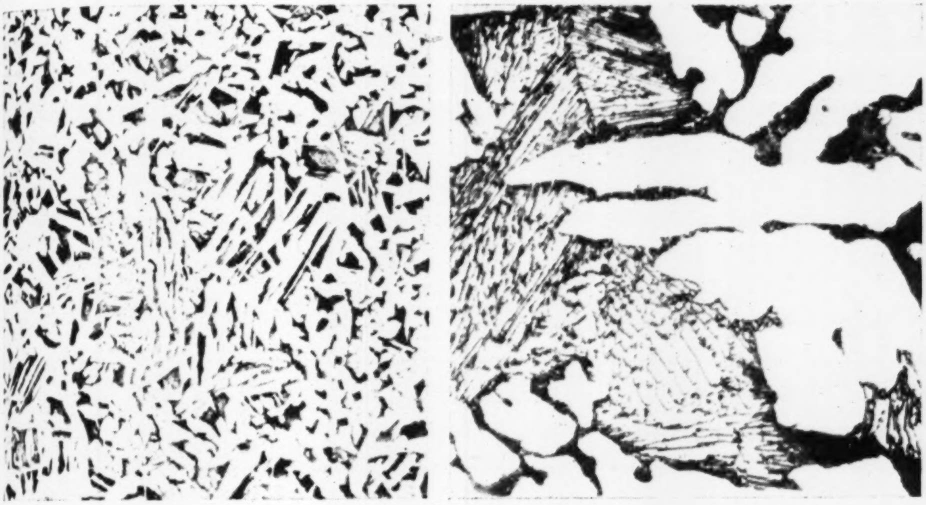


(*b*) Steel E After Test at 850 F. for 900 hr. Under 26,000 psi. Longitudinal Section in Equiaxed Grain Portion of Fractured Specimen. Pearlite Partially Spheroidized.

FIG. 1.—Microstructure of Steel E Before and After Test. Etched in Nital-Picral.

RESULTS AND DISCUSSION

A tracing of a typical elongation-time curve as obtained autographically during a relatively short-time creep-to-rupture test is shown in Fig. 3. On it are indicated the minimum creep rate, the intercept of this rate on the strain axis, and the time of rupture. By plotting the minimum creep rate and the time for rupture against the stress, in the customary way, the stress to produce a specific creep rate, or a specific rupture time, can be determined. In the general case, both types of data are needed for intelligent design of structures to operate at elevated temperature.[3] Of somewhat less importance, though of definite interest, is the relation between fracture-



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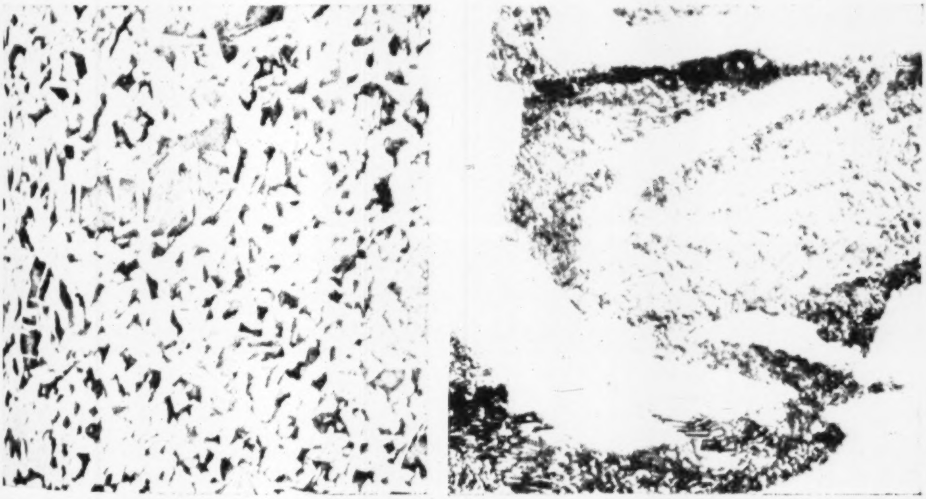
(a) Steel H Before Test. Transverse Section. Note Evidence of Duplex Grain Size and Partial Widmanstätten Structure. Some Pearlite Unresolved.



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(b) Steel H After Test at 850 F. for 750 hr. Under 27,000 psi. Longitudinal Section in Equiaxed Grain Portion of Fractured Specimen. Note Partial Spheroidization.

FIG. 2—Microstructure of Steel H Before and After Test. Etched in Nital-Picral.

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[3] This subject is discussed in somewhat greater detail in reference (6), and in a subsequent section of this paper.

time and the ductility as indicated by the final elongation or reduction of area measured on the fractured specimen.

TABLE II.—SUMMARY OF TEST RESULTS.

Code	Type[a]	Ferrite Grain Size[b]	Room Temperature Hardness DPH (20kg.)	At 850 F.			
				Stress for Rupture, psi.		Stress for Minimum Creep Rate, psi.	
				1000 hr.	10,000 hr.[c]	0.1 per cent per hr.	0.0001 per cent per hr.
A	Cap. O.H.	5 to 7	88	18 000	15 000	19 500	....
B.......	Cap. Bess	4 to 5, 6 to 8	117	21 000	18 000	22 500	....
C.......	Si-Ti O.H.	6 to 8	118	25 500	19 500	29 000	18 000
D.......	Si-Al-Ti O.H.	7 to 8	113	22 500	18 000	25 000	14 200
E.......	Si-Al O.H.	6 to 8	114	26 000	20 000	29 500	19 200
F.......	Si-Al O.H.	8 to 9	145	22 000	17 000	25 000	....
G.......	Si-Al O.H.	7 to 8	124	17 500	13 500	19 000	7 300
H.......	Si O.H.	3 to 4, 6 to 8	137	27 000	22 000	32 000	....
I.......	Si-Al Bess.	7 to 8	130	18 000	13 000	21 000	....
J.......	Si-Al Bess.	7 to 8	129	17 500	13 000	21 000	....
K.......	Si-Al Bess.	7 to 8	140	18 500	12 000	23 000	10 100
L.......	Al Bess.	7 to 9	129	17 000	12 000	20 000	....

[a] Cap. O. H. = capped open-hearth; Al Bess. = aluminum-killed bessemer.
[b] According to A.S.T.M. Charts for Classification of Austenite Grain Size in Steels (E 19 - 46), 1946 Book of A.S.T.M. Standard, Part I-A, p. 682.
[c] Extrapolated.

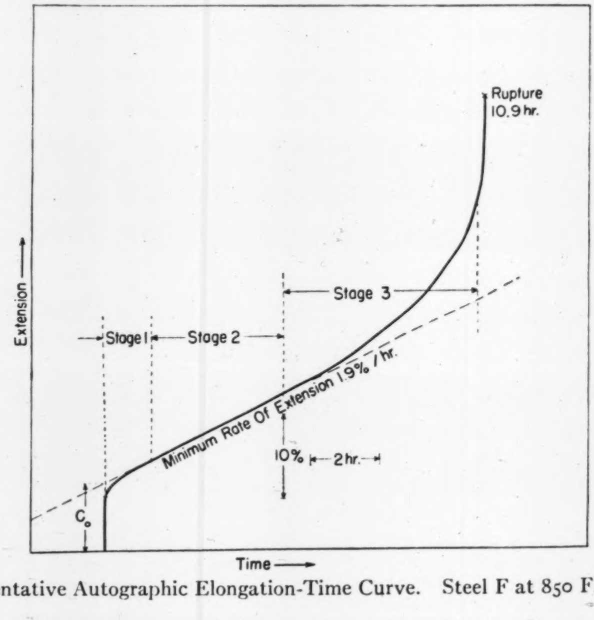

FIG. 3.—Representative Autographic Elongation-Time Curve. Steel F at 850 F. Under 35,000 psi.

Individual graphs showing all these relations for each steel are given in Figs. 4 and 5.[4] From these curves, the stress for rupture in 1000 and 10,000 hr.[5] and for a minimum creep rate of 0.1 and (for five of the steels) 0.0001 per cent per hour have been interpolated and are recorded in Table II to permit ready comparison of the steels. It is of interest to note that in general a steel which has a high creep strength likewise has a high creep-rupture strength, but that neither creep nor creep-rupture strength shows any relation to room temperature hardness.

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[4] Not all tests were continued to rupture, however, and therefore more points will be found on the plots of stress against minimum creep-rate. In general these tests had minimum creep-rates not exceeding 0.001 per cent per hour.

[5] The 10,000 hr. value was obtained by extrapolation.

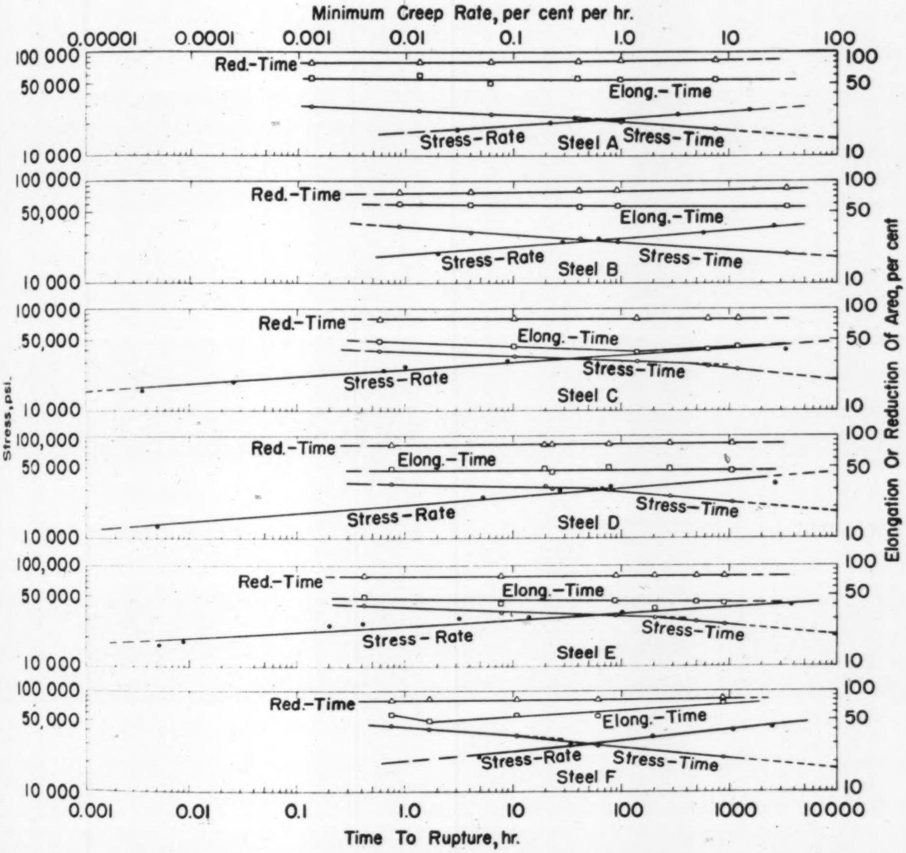

Fig. 4.—Summary Charts Showing the Relation Between Stress, Reduction of Area, or Elongation, and Rupture-Time and Between Stress and Minimum Creep Rate for Steels A to F at 850 F., Compare Fig. 5.

Stress versus Time to Rupture:

The relations between stress and time to rupture, Figs. 4 and 5, proved, when plotted on log-log coordinates, to be a straight line, or two intersecting straight lines, in confirmation of the results of many other investigators. Semi-log plotting did not appear to suit the data as well as log-log plotting, though these data are probably not well suited for distinguishing between the two plots. The occurrence of two intersecting straight lines, in which the longer time portion always has the greater negative slope, has generally been associated in the literature with a change in the path of fracture from transgranular (across the grains) at the shorter time periods to intergranular (at the grain boundaries) at the longer time periods. According to White, Clark, and Wilson (9), and Thielemann and Parker (7), the change in slope is caused by the life-shortening effect of intergranular cracking in an oxidizing atmosphere such as air; in a non-oxidizing atmosphere, intergranular failures appear at the same stress and time, but no change in slope occurs. These relations were established on the basis of a limited number of tests, and should be checked by further studies.

The graphs in Figs. 4 and 5 show slight breaks in the stress-time curve for most of the steels, but in such instances we have not been able to detect any difference in the character of the fracture either by macroscopic or microscopic study. All specimens of a series appeared to "neck in" to an equal degree and examination at high magnification showed severely deformed grains at the fracture with no intergranular cracking, all of which is indicative of transgranular failure. It should be noted that in these

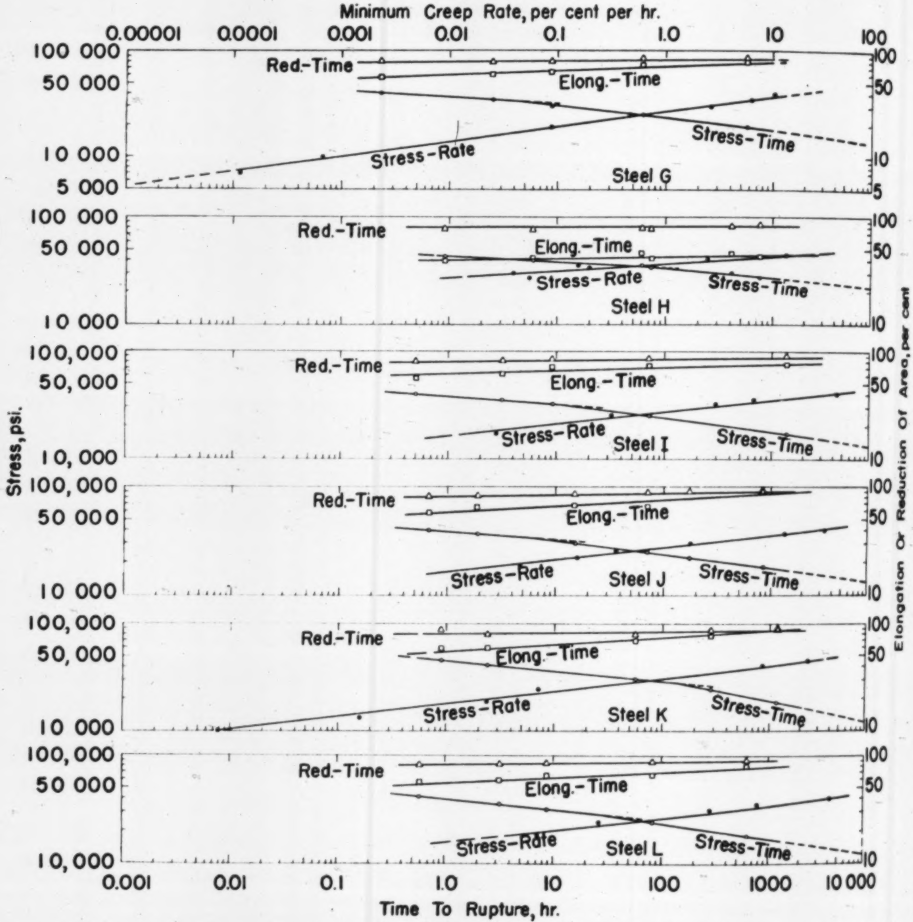

FIG. 5.—Summary Charts Showing Relation Between Stress, Reduction of Area, or Elongation, and Rupture-Time and Between Stress and Minimum Creep-Rate for Steels G to L at 850 F., Compare Fig. 4.

curves the change in slope is quite small.[6] The results of our examination of the fractures are discussed more fully in a following section. In any event, the existence of a linear relation between log-stress and log-rupture time is fortunate in that extrapolation to long service life can be made with some confidence. The possibility of a further break in the curve should, however, not be overlooked, though none has been found by other investigators, as well as in other tests in this laboratory, in tests out to some 10,000 hr.

Stress versus Minimum Rate of Extension:

The relation between stress and minimum creep rate is also a straight line on log-log coordinates, as apparent in Figs. 4 and 5, though the individual points deviate more from the mean than in the previous case. This relation has been generally observed, though data reported by Nadai (8) and others show a tendency for such a curve to turn downward at creep-rates of the order of 0.00001 per cent or less per hour. For such cases, it has been proposed that a hyperbolic sine relation represents the data more accurately. It is interesting to note in Figs. 4 and 5 that the data from the very slow creep tests of steels C, D, E, G, and K at rates approximately 0.0001 per cent per hour align with the faster rate data obtained in the creep-to-rupture tests. Similar agreement was earlier noted in tests of 18 per cent chromium, 8 per cent nickel-molybdinum (A.I.S.I. Type 316) (6). It is also worthy of note that the relative strength of the five steels for which slow rate data are given in Table II is the same at a rate of 0.0001 per cent per hour as at 0.1 per cent per hour. Within what limits this may be generally true is not known since it obviously depends upon the slope of the log-log plot, which differs somewhat from steel to steel.

Ductility versus Time:

The elongation or reduction of area of carbon steel at 850 F. generally either remains substantially unchanged or increases slightly with increasing time to rupture, as apparent in Figs. 4 and 5. This contrasts with the loss in ductility with increasing time generally encountered at higher temperature. For example, White, Clark, and Wilson (9) found a rather sharp drop in elongation or reduction of area with increase of rupture time for carbon steel at 1000 F.

Strength of Carbon Steel at 850 F.:

The data obtained in this investigation show that a remarkable variation in creep behavior of carbon steel exists depending on the mode of manufacture and deoxidation. For the steels here studied, which represent practically the gamut of carbon steels used at elevated temperature, the stress for rupture in 10,000 hr. ranges from 12,000 to 22,000 psi., and the stress to produce a minimum creep rate of 0.1 per cent per hour from 19,000 to 32,000 psi. These steels were selected primarily to cover the whole range of manufacturing and deoxidation practices used for this grade, and secondarily to obtain some information on the reproducibility of properties in heats manufactured and deoxidized in a nominally identical way. Owing to the simultaneous variation of several factors, no attempt has been made to draw any conclusions regarding the effect of individual elements.

The most important factor influencing the creep rate or creep-rupture strength of the steels tested is evidently the deoxidation practice. Excluding the capped steels, the weakest of the open-hearth steels tested, both in creep rate and creep rupture, is steel G, deoxidized with the greatest amount of aluminum, and the strongest in both respects is steel H to which no aluminum was added. However, steel H has the highest carbon content and a duplex grain size and this weakens the comparison. The next strongest open-hearth steel is E, deoxidized with silicon and 1 lb. of aluminum per ton of steel, and this steel, along with similarly strong steels C and D, is also next to H in the series of increasing degree of deoxidation, as judged by the additions. The four highly deoxidized bessemer steels I through L, to each of which was added more aluminum than to any open-hearth steel of the series, were equally low both in creep-rupture strength and creep strength, and the influence of deoxidation practice cannot be judged except by comparison with capped steel B, which was somewhat stronger. The capped steels appear to be in a category of their own, having intermediate to low strength in spite of having had no deoxidizer added. These two steels were the lowest in carbon of those examined, but the specific rôle of carbon is not known. Comparison of the results for steels F and H which were similarly deoxidized suggests that higher carbon and manganese may mitigate the detrimental effect of large aluminum addition.

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[6] We hope to shed more light on this subject in a forthcoming paper describing tests on 18 per cent chromium-8 per cent nickel type steels.

A broad comparison between bessemer and open-hearth processes cannot be made since only the extremes of deoxidation were employed in making the bessemer steels. However, comparison of steel G, the most severely deoxidized open-hearth steel, with bessemer steels I through L shows all to have approximately the same strength. These latter, however, were somewhat more severely deoxidized, as judged by the additions. On the other hand, capped bessemer steel B is slightly superior to capped open-hearth steel A. In this connection, any superiority of the bessemer steel is perhaps to be attributed to the greater amount of phosphorus characteristic of this steel, since this element is generally considered to improve creep strength (10). It seems probable on the basis of the data reported here that method of refining is a factor, but that it is secondary to deoxidation practice.

Since deoxidation practice exerts a very pronounced influence on creep behavior, and since the differences in composition are small and several elements vary in amount simultaneously, it seems impossible to draw any inferences regarding the influence of individual elements. The behavior of steels A and B suggests that phosphorus is beneficial, as pointed out in the preceding paragraph, but this must be based largely on other work, since the strength of bessemer steel may also be affected by the appreciably higher nitrogen of these steels, Table I. For evaluating the influence of individual elements, it would seem necessary to conduct experiments, specifically designed for this purpose, in which very careful attention is paid to control of all variables.

Comparison of steels I, J, and K which are similar in all respects—manufacturing practice, deoxidation practice, composition, hardness and grain size—shows remarkably good agreement in both creep and creep-rupture strengths, and is an indication that the range in properties of carbon steel is attributable to variation in known and controllable variables and not to random, unknown factors.

Examination of Unfractured Specimens:

Notch-impact test specimens of the Charpy keyhole type, and necessarily subsize ($\frac{2}{3}$), were machined from the reduced section of the $\frac{1}{2}$-in. diameter creep specimens that were removed from test before fracture with a permanent elongation of less than 2 per cent. These were tested at room temperature in comparison with similar samples representative of the material prior to creep test to determine whether embrittlement or other changes had occurred during creep-test exposure. Hardness tests were made on these notch-impact samples at a position unaffected by the impact tests. The results of these tests are presented in Table III. Inspection reveals that no very significant changes occurred.

The notch-impact samples were examined microscopically for evidence of microstructural changes which might have occurred during creep-test exposure. Some slight spheroidization of carbide was the only change observed.

TABLE III.—HARDNESS AND NOTCH-IMPACT STRENGTH AT ROOM TEMPERATURE BEFORE AND AFTER CREEP TEST AT 850 F.

Code	Type	Hardness, DPH (20 kg.)		Notch Impact, ft-lb.[a]	
		Before Creep	After Creep	Before Creep	After Creep
C....	Si Ti O.H.	118	116	30.5	24.
D....	Si-Al-Ti O.H.	113	114	34.	35.
E....	Si-Al O.H.	114	119	34.	28.
G....	Si-Al O.H.	124	122	31.	32.5
K....	Si-Al Bess.	140	135	34.	30.5

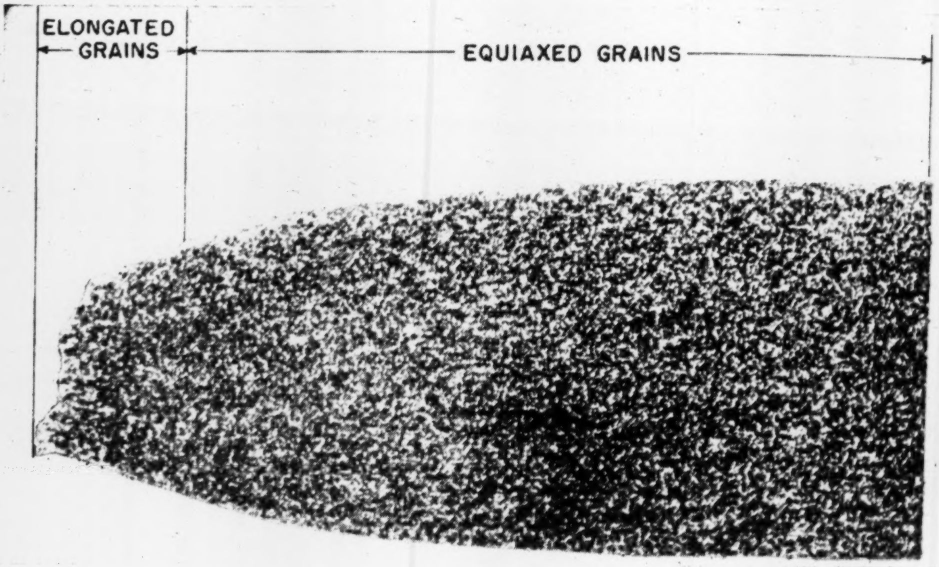
[a] Average of two or more Charpy keyhole tests of ½-size specimens.

Examination of Fractured Specimens:

All of the test specimens "necked-in" at fracture even for the longest test time, some 3500 hr. Since many of the stress *versus* rupture time graphs showed a break, and since, as discussed earlier, this generally has been assumed to correspond to a change from transgranular to intergranular fracture, we prepared and carefully examined with the microscope a longitudinal section through each fracture. Figure 6(*a*) shows the appearance of a typical specimen and illustrates the "necking-in" at the fracture, which was common to all the specimens. As "necking-in" is characteristic of transgranular fracture (11), at least of ductile metals, and since the occurrence of "necking-in" beyond the break is in conflict with the generally assumed significance of the break in the curve referred to above, we had additional reason to examine microscopically the fractured specimens. Such examination failed to show any indication of intergranular failure. In every instance, the necked-down portion of the specimen showed severely elongated grains, fracture appeared to be across the grains, and there were no intergranular cracks back from the fracture or at the surface of the specimen, as generally characteristic, in our experience, of intergranular fracture. The photomicrographs of Fig. 6(*b*) are characteristic of the structure at or near the fracture.

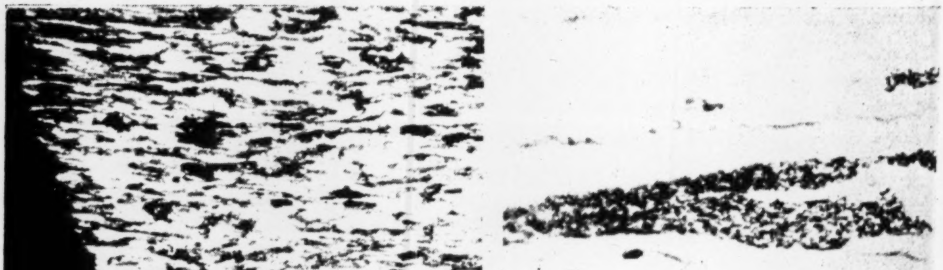
Away from the fracture (Fig. 6(*a*)), the grains were equiaxed as in the undeformed specimen, though of course the deformation in this region is considerably less than at the fracture. The equiaxed grains are more on the order of what might be expected in service, since presumably extension in service will never be as great as in the necked region. Figures 1(*b*) and 2(*b*) show the microstructure of the region of equiaxed grains in relation to the original structures shown in Figs. 1(*a*) and 2(*a*). It is to be noted that some spheroidization has occurred in the instances shown, both of which are relatively long tests, the degree of spheroidization increasing with time of test. No graphite was noted in any specimen either away from or near the fracture.

The fact that, in no instance, did metallographic examination show intergranular fracture is in conflict with the generally accepted significance of the break in the log stress *versus* log rupture-time plot, but as pointed out earlier, the break in no case was very pronounced, and it seems desirable, therefore, to



×10

(*a*) Typical Appearance of a Longitudinal Section Through the Fracture of all of the Specimens Tested.



×100 ×1000

(*b*) Longitudinal Section of Fractured Specimen of Steel E After Test at 850 F. for 900 hr. Under 26,000 psi. Showing Elongated Grains at the Fracture.

FIG. 6.—Characteristics of Fracture of Carbon Steel at 850 F. Etched in Nital-Picral.

await the results of further tests before drawing definite conclusions.

Miller, Smith, and Kehl (11), in controlled strain rate tension tests of molybdenum steel at 850 F., the longest of which required 425 hr. for fracture, found no evidence of other than transgranular fracture at this temperature, yet in similar tests at 1000 and 1100 F. intergranular fracture was observed. White, Clark, and Wilson (9) also found intergranular fractures in carbon steel in long-time creep-rupture tests at 1000 F. or higher, but did not test at lower temperature.

The results of all these tests, and of others, indicate that the type of fracture —transgranular or intergranular—depends both on the temperature and on the time of tests. Intergranular fracture is favored by long time, that is low creep rate, or high temperature. Thus, the higher the temperature, the shorter the test time at which intergranular fracture is to be expected. Again, however, too sweeping a generalization should not be made pending further testing.

Hardness tests were made in the "necked-in" elongated-grain region and in the equiaxed-grain region of the metallographically-prepared fracture sections. Table IV summarizes the results of such measurements on each specimen of steel K. With minor differences, all the other steels behaved similarly. The hardness immediately at the fracture decreases slightly if at all, with increasing time for fracture, whereas the hardness in the equiaxed region decreases to a considerably greater degree. The greater hardness immediately at the fracture is evidently caused by the greater deformation. Whether deformation independent of time at temperature is the only factor active in determining the hardness at any position is not known. It seems more plausible that both time at temperature and deformation are active in the general case, though for the relatively low temperature of 850 F., the latter may be the controlling influence. Certainly if the temperature is sufficiently high and the time sufficiently long, recovery and recrystallization must come into play as deformation proceeds.

Use of Creep Data in Design:

The intelligent choice of working stresses for service at elevated temperature would appear to be conditioned by two limitations, providing it is first recognized that the mere occurrence of creep compels the engineer to design for a specific, rather than an indefinite, life. These limitations are: (1) that within the assumed life, the total creep must not exceed a certain value; for example, so that turbine blades do not jam against the housing; and (2) that within the assumed life, and within the limitation of a specific total creep, the metal does not fracture.

TABLE IV.—HARDNESS OF CARBON STEEL K AFTER CREEP-RUPTURE TEST AT 850 F. INITIAL HARDNESS—140.

Stress, psi.	Rupture-Time, hr.	DPH Hardness (20 kg.)	
		At Fracture	⅛ in. from Fracture
45 000	0.9	238	198
40 000	2.4	239	190
30 000	56.2	235	177
24 000	282.0	231	164
18 000	1180.0	232	156

The majority of data on creep available in the literature are in terms of the stress to produce a minimum creep rate (Fig. 3) of 1 per cent in 10,000 or 100,000 hr., or more properly 0.0001 or 0.00001 per cent per hour. This method of reporting data is inadequate because of uncertainty as to: (1) how long the minimum rate of creep is maintained, (2) the total amount of deformation at the end of the assumed life, and (3) whether the structure will have failed before the end of the assumed life.

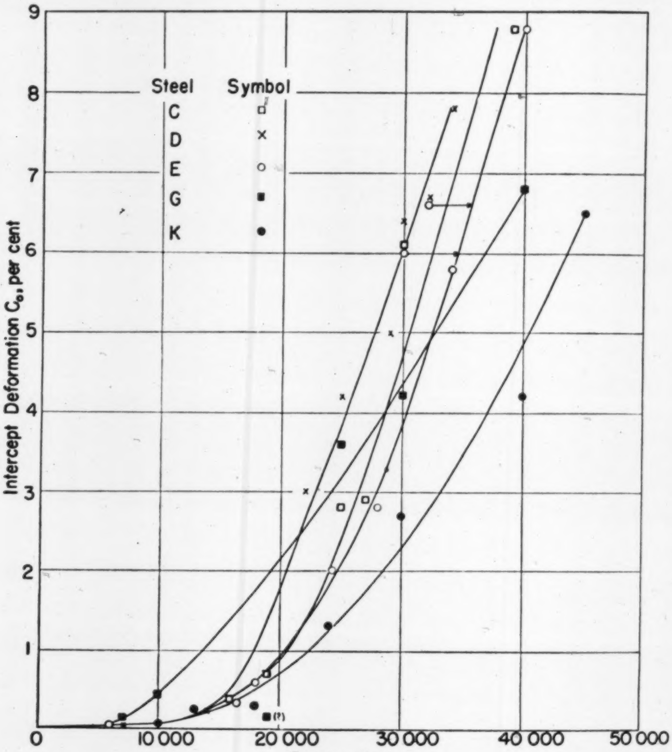


FIG. 7.—Relation Between Stress and Intercept Deformation, C_0 (Fig. 3), for Five Carbon Steels Tested at 850 F.

In recent years more and more creep-rupture data have become available to supplement creep data, and this has removed the uncertainty listed as item 3 above. However, little additional evidence regarding the first two items has become available.[7] Referring to Fig. 3, it is readily apparent that the total extension at any time, at which the minimum creep rate is still existent, is given by the summation of the intercept deformation, C_0, obtained by extending the minimum slope to the ordinate axis, and the deformation obtained by multiplying the minimum rate of extension by the time (12, 13). Accordingly, since there already exists a rather simple relation between stress and minimum creep rate amenable to extrapolation with some confidence (at least within certain limits), all that is required to obtain the total extension at any time (assuming that the third stage is not reached) is a similarly simple relation between the intercept and stress. Figure 7 gives this relation for the five steels for which slow-rate creep tests had been made. Data for the other steels which were tested only to rupture are not presented since no tests were made at low stresses, where interest centers. The curves shown in the plot are similar to ones previously reported by McVetty (12). The data shown in Fig. 7 include both standard creep tests, with direct observation of strain, and creep-rupture tests. The strains for the creep-to-rupture tests, being determined by the fall of the lever (6), have been corrected for the initial elastic extension occurring elsewhere in the apparatus than in the specimen. During test no further strain occurs in the test stand, since the load remains constant. Although some scatter is apparent, the data appear to be well suited for determining total deformation by the means indicated earlier. In many instances the amount of extension represented by the intercept is of minor importance, but in other instances it may be very important.

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[7] A notable exception is the work during and since the War on so-called super-alloys for use in super-chargers, jet propulsion, and similar applications.

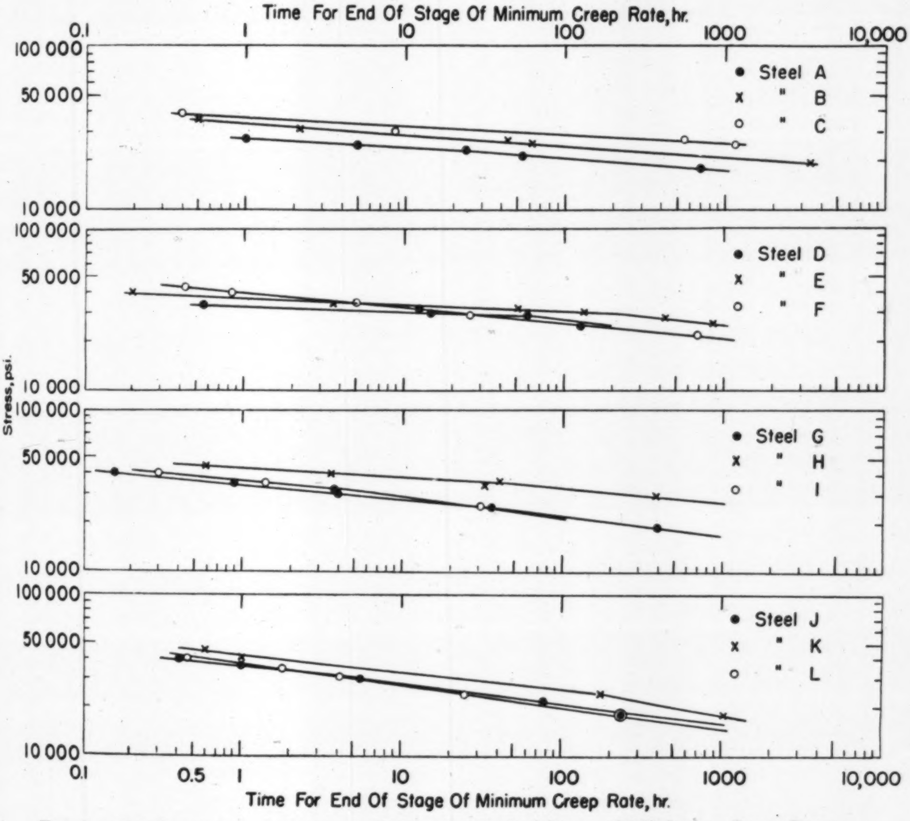

FIG. 8.—Relation Between Stress and Time for End of Stage of Minimum Creep Rate.

Since the previously described means of calculating total creep is limited by the beginning of tertiary or accelerating creep, it is desirable to know when this may be expected. Fortunately, there appears to be a relatively simple relation between this quantity and the stress, (Fig. 8), at least for carbon steel at 850 F. Comparison of these graphs with the stress *versus* rupture-time graphs of Figs. 4 and 5 shows that the stress for the end of the stage of minimum creep rate at any time lies in each case about 1000 psi. below the stress to produce failure in that same time. The data deviate more from the mean than in the graph of time for rupture. This is attributed to the difficulty of determining the onset of tertiary creep in the elongation-time curve. The graphs in Fig. 8 have not been extrapolated because of this deviation and because there is a change in slope near the long-time end of the curves. In other instances, this change or break will undoubtedly be sharper and occur in a shorter time, so that more precise information can be obtained regarding the shape of the curve beyond the break.

SUMMARY

Dependent upon the refining and deoxidation processes, the estimated stress for rupture in 10,000 hr. ranged from 12,000 to 22,000 psi., and the observed stress to produce a minimum creep rate (the so-called second stage of the elongation-time curve) of 0.1 per cent per hour ranged from 19,000 to 32,000 psi.

Excluding capped steel, which was of intermediate strength, and ignoring the possible effect of differences in chemical composition and in structure, the weakest of the open-hearth steels tested was that deoxidized with the greatest amount of aluminum, and the strongest, that deoxidized with silicon but no aluminum. The bessemer steels (other than the capped heat) were similar to one another in degree of deoxidation and showed remarkably uniform results; it is presumed, however, that the rôle of deoxidation in bessemer steels is as important as in open-hearth steel. The agreement in the results of the similarly deoxidized bessemer steels indicates that the range of creep properties in carbon steel can be controlled within narrow limits if warranted, provided attention is given to known variables.

The influence of type of refining process, bessemer or open-hearth, is indicated to be minor, relative to the effect of deoxidation practice, but the range of materials investigated was not sufficiently extensive to permit comparison of open-hearth and bessemer steel over the whole range of deoxidation practice.

The variation in composition was too great and the number of steels too few to permit any conclusions regarding the influence of individual elements, though any such influence within the range of variation of commercial low-carbon steels appears to be minor, relative to deoxidation practice.

The relation between stress and time for rupture, and between stress and minimum creep rate, proved, in confirmation of the results of other investigators, to be relatively simple, being linear on double logarithmic coordinates, Figs. 4 and 5, and therefore suitable for at least limited extrapolation. In this relation, it was observed that minimum creep-rate data obtained for five of the steels at rates on the order of 0.0001 per cent per hour at stresses too slight to produce rupture within an arbitrary 3000-hr. test period, aligned with the faster rate data of the creep-to-rupture tests.

Within the test times here studied, the elongation and reduction of area remained substantially constant, and the type of fracture remained transcrystalline throughout. All specimens "necked in" and showed severely elongated grains at the fracture. Some slight spheroidization, but no graphitization, was encountered, particularly in the longer time tests. Notch-impact and hardness tests on specimens prepared from creep tests discontinued prior to rupture indicated that no important deterioration in ordinary mechanical properties occurred (Table III).

The relation between stress and the end of the period of minimum or uniform creep-rate is indicated by comparison of Fig. 8 with Figs. 4 and 5, to be nearly identical in character with that between stress and rupture time, the curve for the former lying, for the steels tested, some 1000 psi. below the latter at any specific time.

Acknowledgments:

The National Tube Co. furnished the steels studied in this investigation. R.

F. Miller participated in the initial stages of the test program. Messrs. R. B. Wallace and E. G. Houston and Miss S. H. Brambir assisted in the testing.

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DISCUSSION

Mr. H. C. Cross.[1]—I have been interested in the subject of the effect of deoxidation practice on the creep properties of carbon steels for some years, and I have looked this paper over with a great deal of interest.

I arranged the steels given in Table II in the order of their rupture and creep strengths. The best steels are those which are silicon deoxidized, or silicon deoxidized with moderate aluminum additions. The four best ones are H, E, C, and D; two of these four had only silicon or silicon-titanium additions. The other two had either ½ or 1 lb. per ton of aluminum added, and those amounts of aluminum did not seem harmful.

The balance of the steels of somewhat lower strengths had considerably higher aluminum additions with about the same silicon additions as in the steels with the higher properties.

This suggests there may be a relationship between silicon and aluminum and their effect on creep properties. This should be looked into from a fundamental standpoint. It should be determined whether a steel with an aluminum addition of more than 1 lb. per ton would still have good creep properties if the silicon was increased sufficiently.

So I am suggesting to the ASTM-ASME Joint Committee on Effect of Temperature on the Properties of Metals that steels be obtained with silicon additions of 0.35 to 0.40 per cent in one series and 0.50 to 0.60 per cent in another series, with the idea of obtaining silicon-aluminum ratios at a rather high level.

The best four steels tested by Smith and Dulis have silicon-aluminum ratios ranging from 25 to 50; that is, the silicon content divided by the aluminum content gave ratios of 25 or more. All of the steels with poor properties have silicon-aluminum ratios of 10 or less.

So I am suggesting to the Joint Committee that we determine whether silicon and aluminum are related, and whether if their ratio be properly balanced, good creep properties may be obtained in an aluminum-treated, fine-grained carbon steel.

Mr. G. V. Smith (*author*).—We shall be interested in learning the results of the tests which Mr. Cross proposes to make to test the idea that the creep strength of these steels is related to the ratio of the silicon and aluminum contents.

Mr. John Howe Hall.[2]—At one time, bessemer steel, particularly side-blown bessemer steel, was supposed to be inferior to open-hearth and electric-furnace steel; but a few years ago, as you all know, it was demonstrated by very careful tests, that in most respects side-blown converter cast steel is in no way inferior to electric-furnace or open-hearth cast steel. These tests unfortunately did not cover creep properties. No data on creep strength of converter cast steel have ever been published, but the "grape-vine" has spread the word that the strength of side-blown converter cast steel, for a given rate of creep, is low.

It happens that in all side-blown converter steels made for castings, including those tested for creep, the aluminum addition is very high. I have always been anxious to see if it is possible to make side-blown converter steel for castings with much more silicon and much lower aluminum than are usually added, and whether, in that case, the creep strength of that steel would not be as high as that of open-hearth or electric-furnace steel.

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[1] Supervisor, Battelle Memorial Inst., Columbus, Ohio

[2] Steel Foundry Consultant, Swarthmore, Pa.

What brought that to my mind was that, in this paper, I notice in every case very high aluminum additions were made to the bessemer steel. I should like to ask the authors if it was necessary to add so much more aluminum to the bessemer steel than to the open-hearth steel in order to prevent porosity and to keep the steel from rising in the ingot molds.

MR. SMITH.—In reply to Mr. Hall, the relatively large aluminum additions to the "killed," deoxidized, bessemer steels were made primarily to obtain desirable material characteristics, such as minimum susceptibility to strain-aging embrittlement.

THE EFFECTS OF TEMPERATURE AND MATERIAL STRUCTURE ON THE FRACTURE PROPERTIES OF MEDIUM-CARBON STEEL[*][1]

By Julius Miklowitz[2]

Synopsis

In this work, variations in the temperature of testing, size of grain, and type of pearlite in the structures of a silicon-killed and silicon-aluminum-killed steel have produced differences in the ductility and strength values of these two materials. Tension tests have indicated that at all temperatures (1) a high strain at fracture in the minimum section of the neck favored in general the spheroidized pearlite and fine-grained structure and the silicon-killed steel, and (2) a high average true stress at fracture in the minimum section of the neck favored the fine-pearlitic structure and the silicon-aluminum steel. Grain size did not have a large effect on the fracture stress.

For all types of material structure and in both steels (1) the fracture stress increased with a decrease in temperature of testing (from 24.5 to −65 C.) and (2) the strain at fracture decreased with a decrease in temperature of from −20 to −65 C.

A series of Charpy impact tests showed the fine grain and fine or spheroidized pearlite best for low temperature toughness. The severest drop in impact energy for all types of material structure and for both steels came with decreasing the temperature from ambient to 0 C. Further temperature decreases had a similar but less pronounced effect on the impact energy.

The decrease in ductility in the tension tests, with a decrease in temperature and change in material structure, was accompanied by a transition from the ductile cup-and-cone fracture to a fracture of abrupt crystalline nature. A similar phenomenon was apparent in the drop of the impact energy with temperature.

This paper presents the results of an investigation designed to survey briefly two factors that are influential in causing a normally ductile material to fracture in a brittle manner. The vast amount of literature on the subject of brittle fracture in steels,[3] which essentially deals with notch-impact testing, both tension and bending, points out that the material structure and testing temperature are important variables. The present work deals with the influence of these two factors on the transition from ductile to brittle failure in the ordinary tension bar. The stress-strain diagrams and resulting fractures of specimens differing in type of pearlite and size of grain at temperatures from −65 C. to the ambient value of 24.5 C. have shown that the material structure and testing temperature have definite effects on the ductility and strength properties of these steels. The specimens were made from two steels which differed in grain-coarsening characteristics due to diverse methods of killing.

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[*] Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] The experimental work of this investigation was carried out at the Westinghouse Research Laboratories, East Pittsburgh, Pa., during 1945 and 1946, under a contract with the David Taylor Model Basin of the Navy Department, Bureau of Ships, Washington, D. C.

[2] Research Engineer, Westinghouse Research Laboratories, East Pittsburgh, Pa.

[3] The reader will find a discussion of the problems in this subject along with a condensed review of the literature in the following survey: M. Gensamer, E. Saibel, J. T. Ransom, and R. E. Lowrie, "Report on the Fracture of Metals—Parts I and II," *Welding Research Supplement, Journal*, Am. Welding Soc., Vol. 26, p. 443s (1947).

The body of this paper is divided into discussions of strain, stress, and impact strength, the latter being a report of a series of Charpy tests which were also included in the testing program.

TENSION TEST APPARATUS, SPECIMEN, AND TESTING PROCEDURE

The 10-ton constant-strain-rate machine, its sensitive electrical extensometer, and automatic load-elongation recorder used in this work are discussed in a previous paper by the author.[4] The machine was specially equipped with a direct motor drive which enabled the

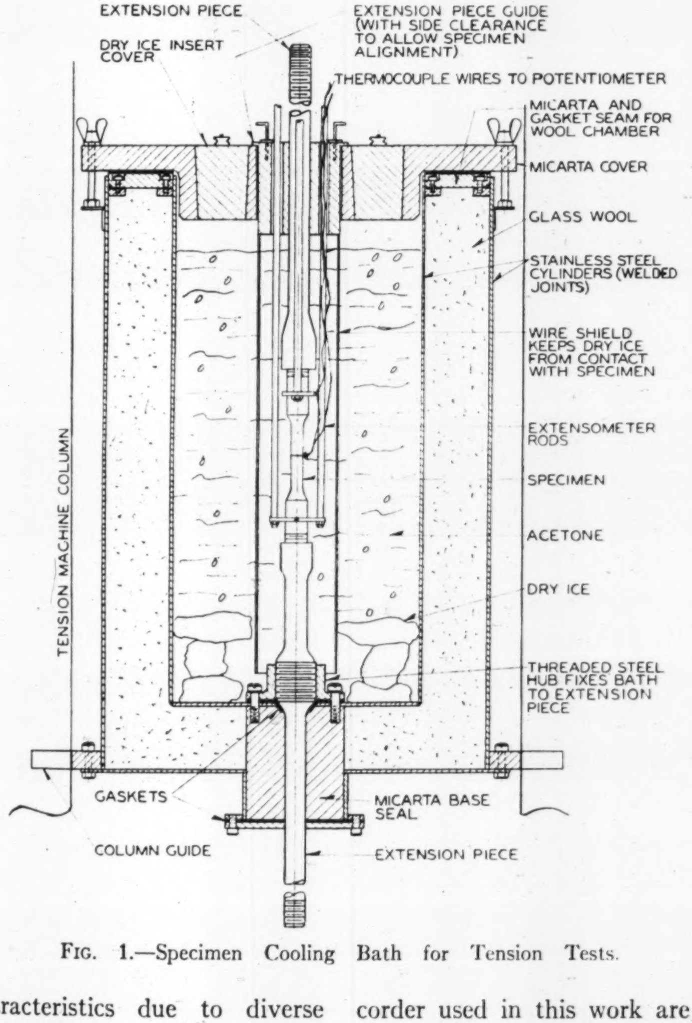
EXTENSION PIECE
DRY ICE INSERT COVER
EXTENSION PIECE GUIDE (WITH SIDE CLEARANCE TO ALLOW SPECIMEN ALIGNMENT)
THERMOCOUPLE WIRES TO POTENTIOMETER
MICARTA AND GASKET SEAM FOR WOOL CHAMBER
MICARTA COVER
GLASS WOOL
STAINLESS STEEL CYLINDERS (WELDED JOINTS)
WIRE SHIELD KEEPS DRY ICE FROM CONTACT WITH SPECIMEN
EXTENSOMETER RODS
SPECIMEN
ACETONE
DRY ICE
THREADED STEEL HUB FIXES BATH TO EXTENSION PIECE
TENSION MACHINE COLUMN
GASKETS
MICARTA BASE SEAL
COLUMN GUIDE
EXTENSION PIECE

FIG. 1.—Specimen Cooling Bath for Tension Tests.

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[4] J. Miklowitz, "The Initiation and Propagation of the Plastic Zone in a Tension Bar of Mild Steel under Eccentric Loading," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 69, p. A21 (1947).

tests to be made at a faster rate of stretching than ordinarily employed in this machine. The average rate of strain in the tests was approximately 0.018 in. per in. per sec. Figure 1 illustrates the cooling bath which kept a constant temperature of testing about the specimen throughout the rather fast test. Dry ice (carbon dioxide) sublimation within the liquid body of acetone in this bath cooled the liquid down as far as −70 C. The bubbling of the excess dry ice at the bath bottom created enough agitation to keep a constant bath temperature. Preliminary checks showed no temperature variation over the gage length of the specimen. A wire screen around the test specimen, thermocouple wires, and extensometer parts kept the dry ice from any possible contact with these parts. The bath, made of two welded stainless steel cylinders separated by an air-tight insulating chamber filled with glass wool, was fixed to the lower head of the machine. Its lower end was guided by the two adjacent columns. The bath moved with the lower head, its upper end being guided by the upper extension piece over which it passed. The extensometer rods, fixed to their respective positions on the specimen, projected out of the bath through holes in the upper extension piece guide. The temperature was measured by means of a thermocouple and potentiometer. Gaskets and Micarta seals were used at various places in the bath to insure air tightness and to prevent fluid leakage. The holes cut in the Micarta cover afforded insertion of the dry ice at the necessary intervals.

The bath was used for two series of tests: a group that had an average temperature of −65 C. and a group of an average temperature of −20 C. A series of tests at ambient temperature was also made. The stress-strain data were obtained from the automatic load-elongation records and measurements on the specimen after testing.

The specimens used were of the type shown in Fig. 2. They were heat treated previous to machining to obtain the various structures described below. The thermocouple was mounted at the center of the gage length.

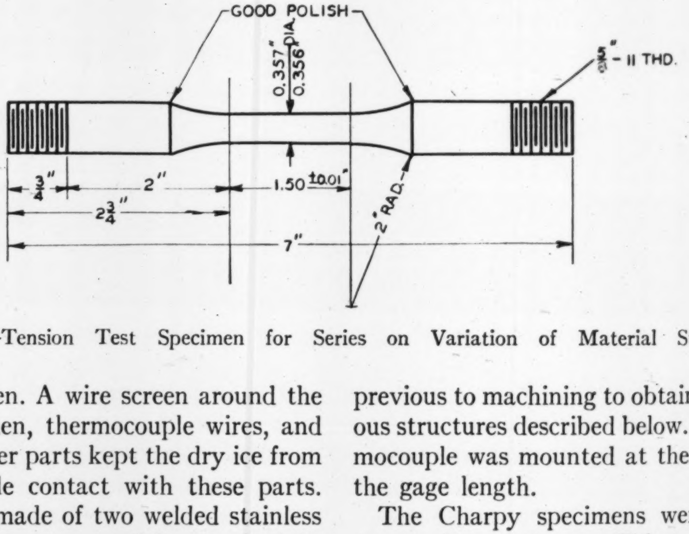

FIG. 2.—Tension Test Specimen for Series on Variation of Material Structure.

The Charpy specimens were of the standard V-notch type. This was selected since, in a review of the report by Gillett and McGuire[5], it was mentioned that this type notch more readily shows the transition from ductile to brittle fracture than the round keyhole notch. The method employed in cooling the Charpy specimens was similar to that for the tension specimens. The thermocouple was spot-welded to the specimen in the series of tests at the very lowest temperatures. The specimen was hurriedly taken from the bath, placed on the anvils of the Charpy machine, and broken when the galvanometer needle reached the 0 mark for the specific temperature (−75 C.) that was set on the potentiometer. At the higher temperatures, the rate of heating in the transfer from bath to machine was determined, and then just the bath temperature was recorded. Corrections were then made for the change in temperature of the specimen in the transfer.

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[5] H. W. Gillett and F. T. McGuire, "Behavior of Ferritic Steels at Low Temperatures, Parts I and II," Report of War Metallargy Committee, W-78 (1944), Am. Soc. Testing Mats. (1945). (Symposuim issued as separate publication, *STP No. 63*).

TABLE I.—HEAT TREATMENTS AND RESULTING STRUCTURES.

Type	Heat Treatment			Resulting Structure		
	Temperature, deg. Fahr.	Time, hr.	Quench	Pearlite	Prior Austenitic Grain Size (A.S.T.M.)[c]	Remarks
I2[a]........	1500	1	Oil	Fine	6.5 (Fine)	
I8........	2000	1	Oil	Fine	3.0 (coarse)	
I1........	1500	1	Furnace cool	Coarse	6.5	Banded pearlite; 29 bands in field of microscope.
I7........	2000	1	Furnace cool	Coarse	3.0	Banded pearlite; 14 bands in field of microscope.
I3........	1500	1	Oil, tempered 24 hr. at 1275F.	Spheroidized	6.5	
I9........	2000	1	Oil, tempered 24 hr. at 1275F.	Spheroidized	3.0	
J1[b]........	1600	1	Furnace cool	Coarse	8.0 (fine)	Banded pearlite; 44 bands in field of microscope.
J4........	2000	1	Furnace cool	Coarse	8 + > 0 (mixture)	Banded pearlite; 14 bands in field of microscope. "Duplexed" steel.

[a] The "I" designation refers to the steel supplied as follows: open hearth, medium carbon (0.26) and Si-killed (gradually coarsening grain characteristics).

[b] The "J" designation refers to the steel supplied as follows: open hearth, medium carbon (0.24), and Si-Al-killed (abruptly coarsening grain characteristics).

[c] Classification of Austenitic Grain Size in Steels (E 19-46), 1946 Book of A.S.T.M. Standards, Part I-A, p. 682.

MATERIAL, HEAT TREATMENTS AND RESULTING STRUCTURES

The work of Gillett and McGuire[5] mentioned previously was helpful in the selection of the steels used in this investigation. Their report on impact properties brings out the importance of proper deoxidation and heat treatment in producing fine-grained steels of low-temperature toughness.

The two steels were supplied by the Carnegie-Illinois Steel Corp. They were medium-carbon steels of open hearth production. One was silicon-killed to produce a steel of gradually coarsening grain characteristics, the other was silicon-aluminum killed to produce a steel of abruptly coarsening characteristics. Bain[6] describes the differences of the grain coarsening characteristics in these two types of steels. The silicon-killed steel coarsens gradually as the heating temperature increases. The silicon-aluminum-killed steel remains of fine grain structure throughout most of the heating range (from approximately 1350 to 1900 F.), and then abruptly coarsens at higher temperatures. At these higher heating temperatures, a "duplexed" steel is sometimes produced, in which two sizes of grains are present. When the steels are heated high enough (over 2000 F.), both types become completely coarse grained. The composition of the silicon-killed steel was as follows: C 0.26, Mn 0.68, P 0.017, S 0.027, Si 0.20 per cent. The silicon-aluminum-killed steel had the following composition: C 0.24, Mn 0.66, P 0.019, S 0.030, Si 0.22 per cent.

Table I lists the various heat treatments used in this work. The resulting structures are also tabulated. The "I" designation refers at all times to the silicon-killed steel of gradually coarsening grain characteristics, the "J" designation to the silicon-aluminum-killed steel of abruptly coarsening characteristics. The lower heat treating temperatures produced the fine-grained structure, the higher, the coarse-grained structure in all cases. The quenching or the cooling rate determined the condition of the resulting pearlite lamellae. The fast rate of cooling (oil quench) produced a fine pearlite. The slow rate of cooling (furnace cool) produced a coarse pearlite. The spheroidized pearlite was made by tempering back, for 24 hr. at 1275 F., an oil-quenched steel. The table shows that in the use of J4 a "duplex" steel was produced.

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[6] E. C. Bain, "Functions of the Alloying Elements in Steel," A Book of the lectures presented to the Am. Soc. Metals at their twenty-first National Metal Congress and Exposition, Chicago, Ill., pp. 133–138 (1939).

The different structures were tested in order to determine the influence of the grain size (prior austenitic—A.S.T.M.),[7] type of pearlite, and method of killing, on the ductility and strength properties in medium-carbon steels. The first two factors reflect the component parts of heat treatment, namely, temperature, rate of cooling, and tempering. The steels were also tested in their "as-rolled" condition.

The photomicrographs of the various structures are presented in Figs. 3 to 7, inclusive. Magnifications of 1000× and 100× are shown for each type of heat treatment. The 1000× magnifications bring out the type of pearlite, and the 100× the grain size and type of structure. The coarse pearlitic structures are seen to be of a nature in which the pearllite lies in bands. The degree of fineness of these bands reflects the grain size (Figs. 4 and 6). The grain size differences of type I2 and I8, the fine pearlitic structures, can be readily seen. The same is true of type I3 and I9, the spheroidized pearlite samples.

METHOD OF COMPARING PROPERTIES

The data obtained have been classified in the categories on which the comparisons are based, namely; the type of pearlite, the grain size and the types of steels (Figs. 8 to 11). Two curve sheets are presented for each property studied. In the (*a*) part of each figure, the variations of the property with temperature and type of pearlite are shown in two groups: one for the fine-grained steel, the other for the coarse-grained steel. Separation into these two groups enabled a comparison on the basis of the pearlite alone to be made since in each group the grain size was the same. Only the "I" type steel (gradually coarsening grain characteristics) was used in the pearlite comparison. The (*b*) part of each figure has plots that compare the particular property on the basis of grain size. Each of the groups here have the pearlite the same within them. Both steels are shown in this part of the figure including the "as-rolled" tests. They can best be compared through the J1 and I1 structures (both fine grain-coarse pearlite). Each point on the curves is a test at a particular temperature; the points on any one curve are naturally of specimens of the same structure. The "I" curves appear in both parts (*a*) and (*b*) of the figure.

Two strain quantities have been used to represent the ductility. The strain in the minimum section of the neck at fracture, based on the relation $\epsilon = \frac{A_o}{A} - 1$, A_o and A being original and final areas of the section, has been plotted against the temperatue of testing. It is an important quantity in that it reflects the type of fracture and amount of necking previous to fracture. The ordinary conventional strain at the ultimate load is also plotted. It is based on the usual relation $\epsilon = \frac{l - l_o}{l_o}$, where l_o is the original

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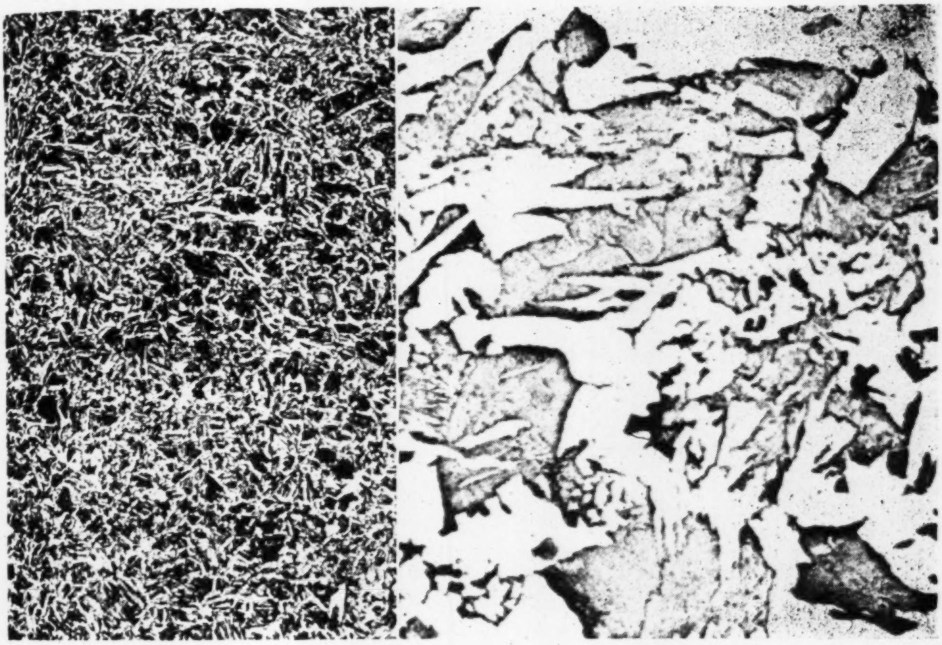
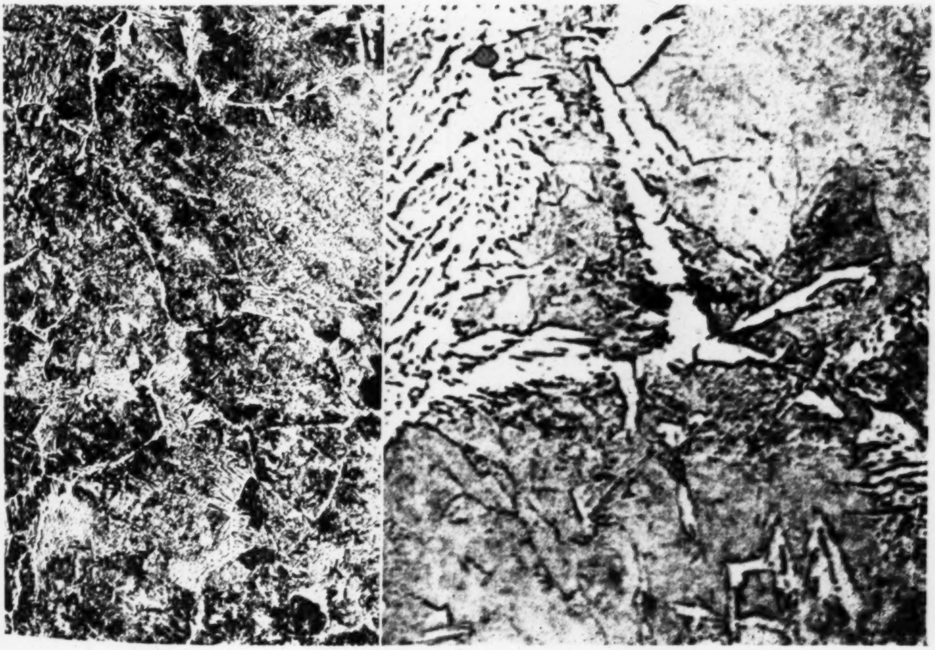
[7] Classification of Austenitic Grain Size in Steels (E 19-46), 1946 Book of A.S.T.M. Standards, Part I-A, p. 682.



(×100) (×1000)

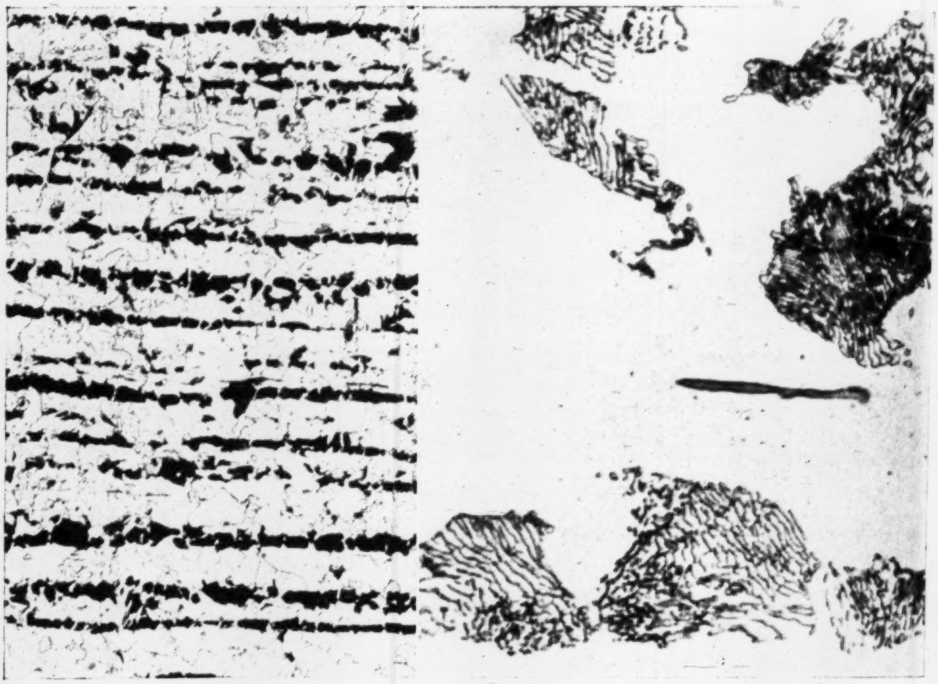
(*a*) Fine Grain (6.5 A.S.T.M.) Type I2. Treatment: 1 hr. at 1500 F., oil quench. Etched in Picral.



(×100) (×1000)

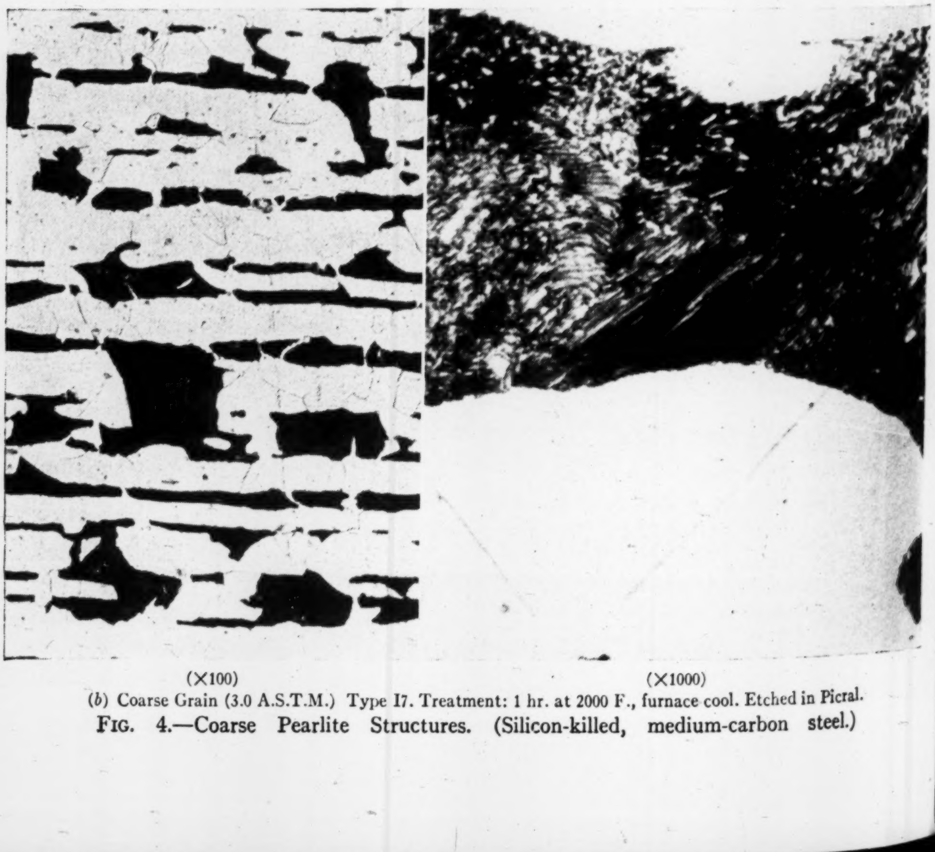
(*b*) Coarse Grain (3.0 A.S.T.M.) Type I8. Treatment: 1 hr. at 2000 F., oil quench. Etched in Picral.

FIG. 3.—Fine Pearlite Structures. (Silicon-killed, medium-carbon steel.)



(×100) (×1000)

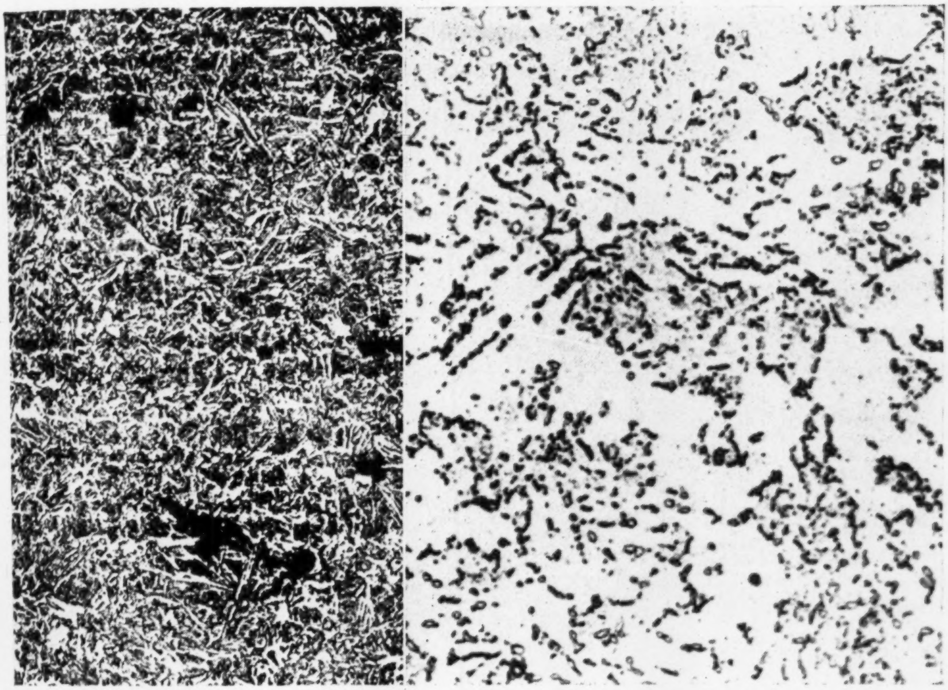
(*a*) Fine Grain (6.5 A.S.T.M.) Type I1. Treatment: 1 hr. at 1500 F., furnace cool. Etched in Picral.



(×100) (×1000)

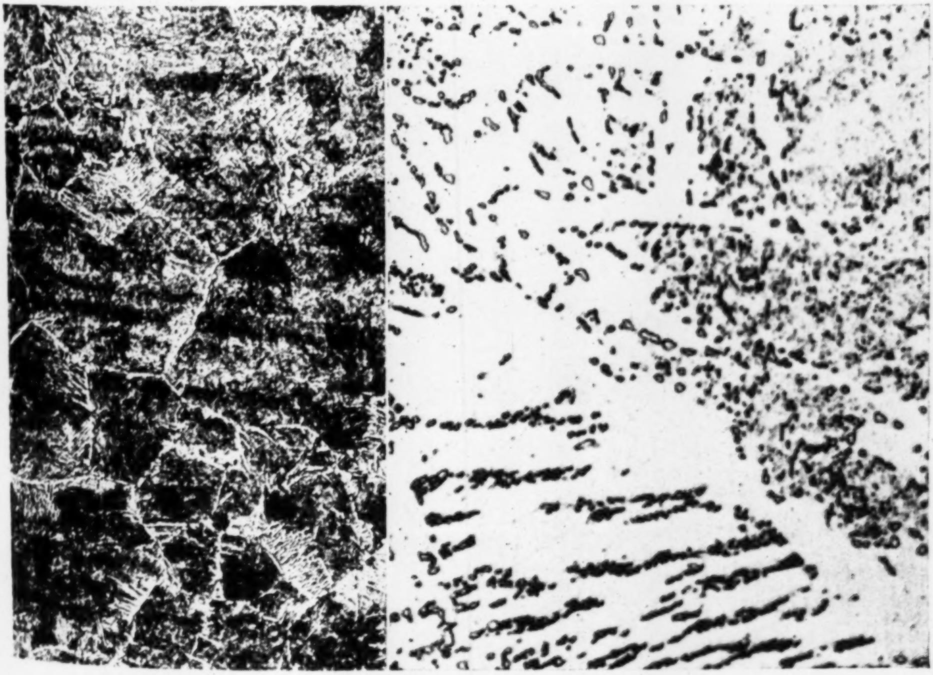
(*b*) Coarse Grain (3.0 A.S.T.M.) Type I7. Treatment: 1 hr. at 2000 F., furnace cool. Etched in Picral.

FIG. 4.—Coarse Pearlite Structures. (Silicon-killed, medium-carbon steel.)



(×100) (×1000)

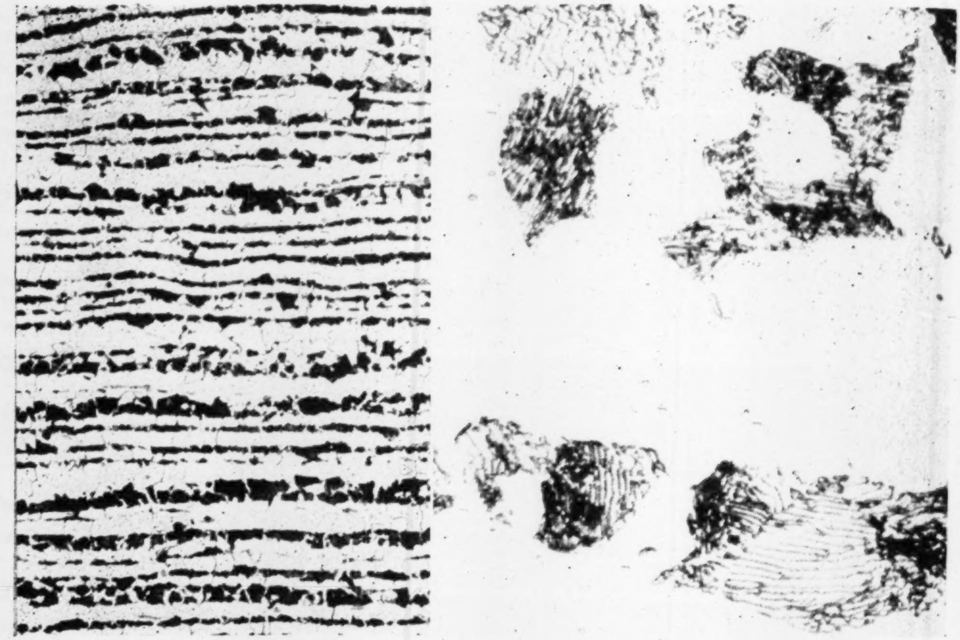
(*a*) Fine Grain (6.5 A.S.T.M.) Type I3. Treatment: 1 hr. at 1500 F., oil quench and tempered 24 hr. at 1275 F. Etched in Picral.



(×100) (×1000)

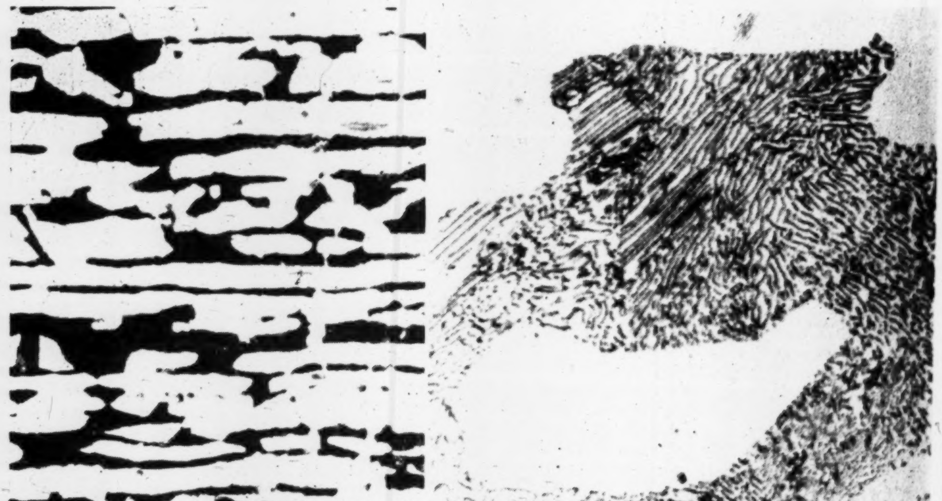
(*b*) Coarse Grain (3.0 A.S.T.M.) Type I9. Treatment: 1 hr. at 2000 F., oil quench and tempered 24 hr. at 1275F. Etched in Picral.

FIG. 5.—Spheroidized Pearlite Structures. (Silicon-killed, medium-carbon steel.)



(×100) (×1000)

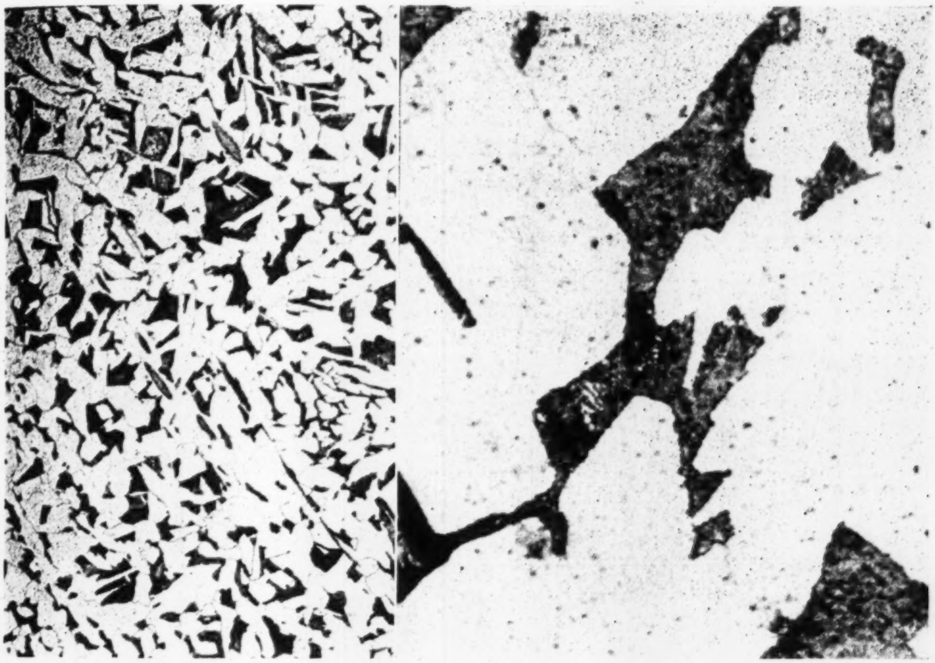
(*a*) Fine Grain (8.0 A.S.T.M.) Type J1. Treatment: 1 hr. at 1600 F., furnace cool. Etched in Picral.



(×100) (×1000)

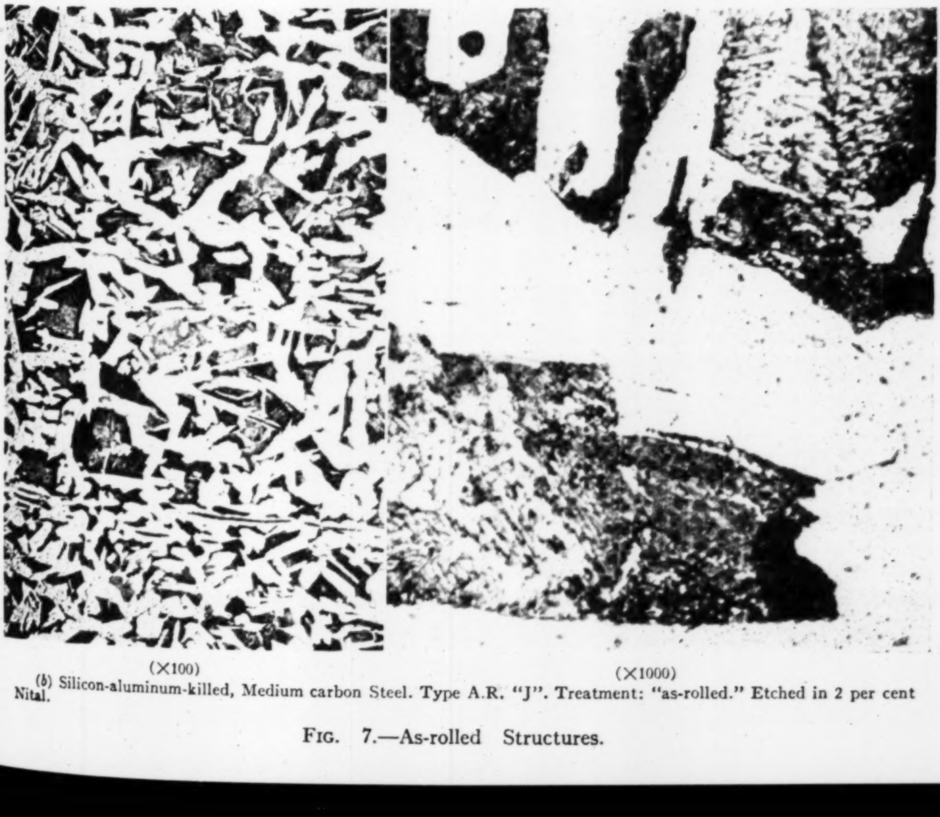
(*b*) "Duplexed" Grain (8 + > 0 A.S.T.M.) Type J4. Treatment: 1 hr. at 2000 F., furnace cool. Etched in Picral.

FIG. 6.—Coarse Pearlite Structures. (Silicon-aluminum-killed, medium-carbon steel)



(×100) (×1000)

(*a*) Silicon-killed, medium-carbon steel. Type A.R. "I" Treatment: "as-rolled." Etched in 2 per cent Nital.



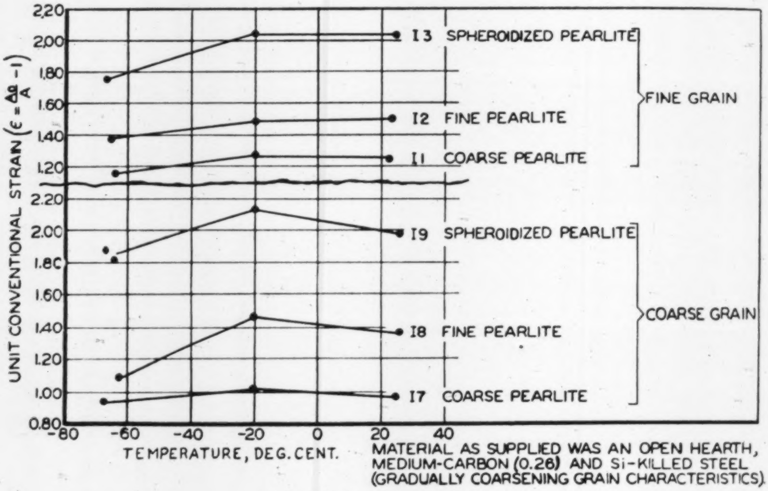
(×100) (×1000)

(*b*) Silicon-aluminum-killed, Medium carbon Steel. Type A.R. "J". Treatment: "as-rolled." Etched in 2 per cent Nital.

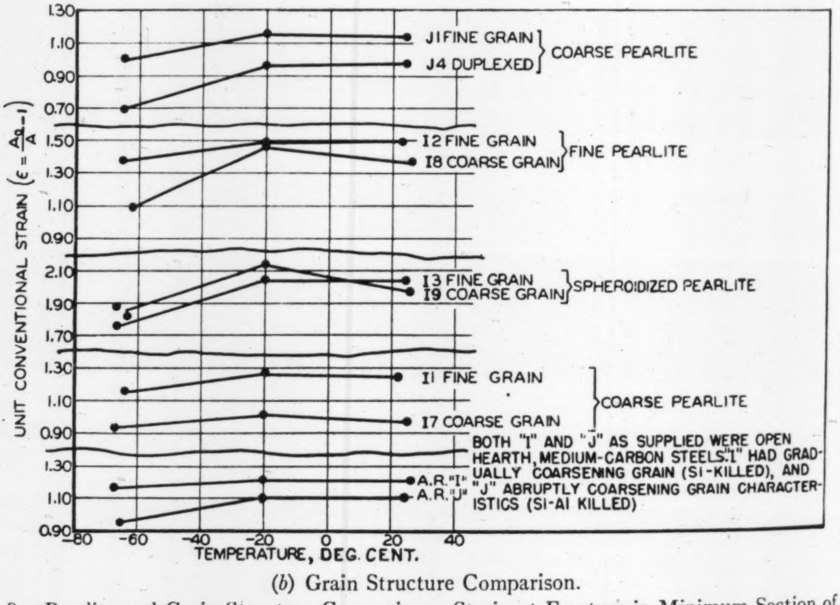
FIG. 7.—As-rolled Structures.

gage length of specimen and l its final length.

Two stress values have been plotted as functions of temperature for the various material structures, the average true stress at fracture in the minimum section of the neck, and the true stress at the ultimate load. They are based on the relation $\sigma = \frac{P}{A}$, where P is the load acting on A, the particular strained area in question.



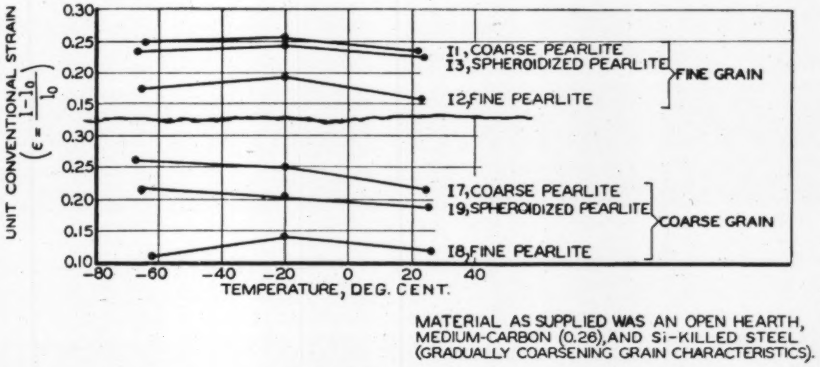
(*a*) Pearlite Comparison.



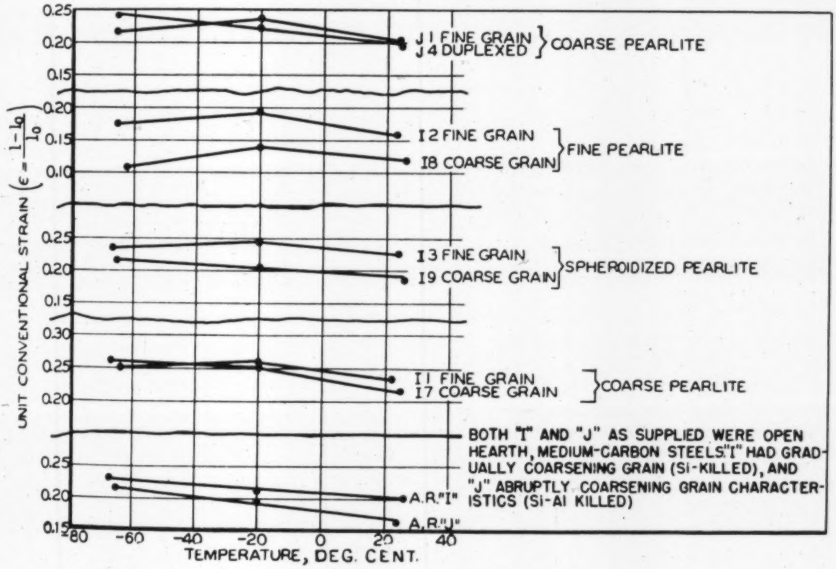
(*b*) Grain Structure Comparison.

FIG. 8.—Pearlite and Grain Structure Comparison—Strain at Fracture in Minimum Section of the Neck As a Function of Temperature.

The Charpy impact energy variations with temperatue and material structure have been plotted and are shown in Fig. 12.



(*a*) Pearlite Comparison.



(*b*) Grain Structure Comparison.

FIG. 9.—Pearlite and Grain Structure Comparison—Strain at Ultimate Load as a Function of Temperature.

DISCUSSION OF RESULTS

Aspects of Ductility:

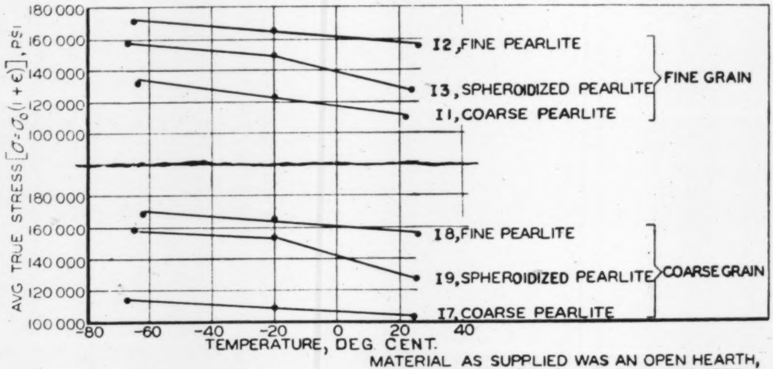
Test results are presented in Figs. 8 to 12. The ductility of medium-carbon steel, as represented by the conventional axial strain in the minimum section of the neck of a tension specimen at fracture, was found to be greatest for the spheroidized pearlite structures. This is shown in Fig. 8. Both the fine and coarse grained, made from a silicon-killed steel, showed the highest strain values of the various structures tested at all temperatures. In this type of pearlite no great difference due to grain size changes occurred at any temperature. Table II indicates that the ductile cup and cone fracture occurred at every temperature for the spheroidized pearlite. Next highest in ductility are the fine pearlitic structures. In this group, and the group of

TABLE II.—TYPE OF FRACTURE AS INFLUENCED BY TEMPERATURE AND MATERIAL STRUCTURE.

Type of Heat-Treatment and Resulting Structure	Pearlite	Grain Size	Temperature of Testing, deg. Cent., at which the Following Types of Fracture Occurred:		
			Ductile Cup and Cone	*Mixture* Cup and Cone plus Brittle Crystalline Tendencies	*Brittle* Crystalline Abrupt Tear
I9	Spheroidized	Coarse	24.5, −20, −65	....	....
I3	Spheroidized	Fine	24.5, −20, −65	....	....
I2	Fine	Fine	24.5, −20, −65	....	....
*A.R. "I"	....	....	....	24.5, −20	−65
I1	Coarse	Fine	....	24.5, −20	−65
I8	Fine	Coarse	....	24.5, −20	−65
J1	Coarse	Fine	....	24.5	−20, −65
*A.R. "J"	....	....	....	24.5	−20, −65
I7	Coarse	Coarse	....	....	24.5, −20, −65
J4	Coarse	Duplexed	....	....	24.5, −20, −65

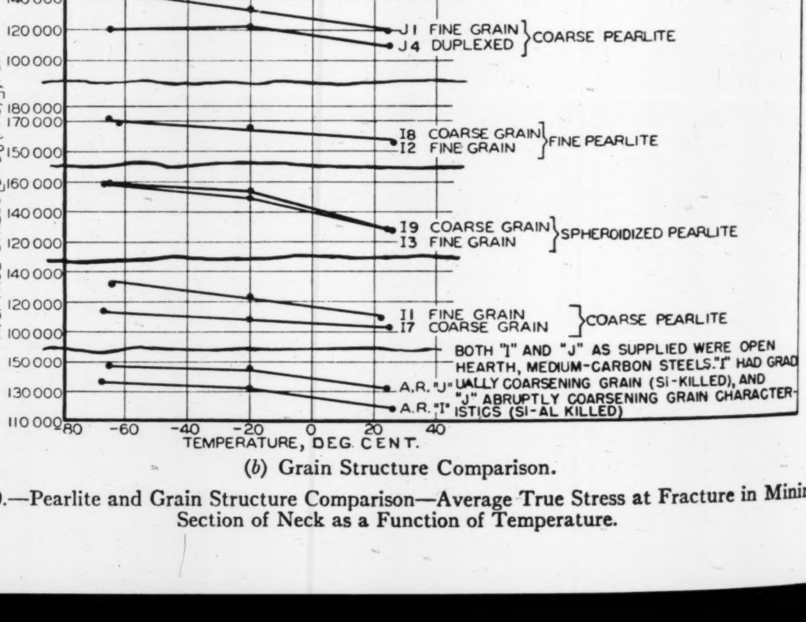
NOTE.—In every case the specimen tested at −65 C. had a seemingly coarser-grained appearance on its fracture surface than those at the higher temperatures.

* A.R. = As rolled (hot rolled).



MATERIAL AS SUPPLIED WAS AN OPEN HEARTH, MEDIUM-CARBON (0.26), AND Si-KILLED STEEL (GRADUALLY COARSENING GRAIN CHARACTERISTICS).

(*a*) Pearlite Comparison.

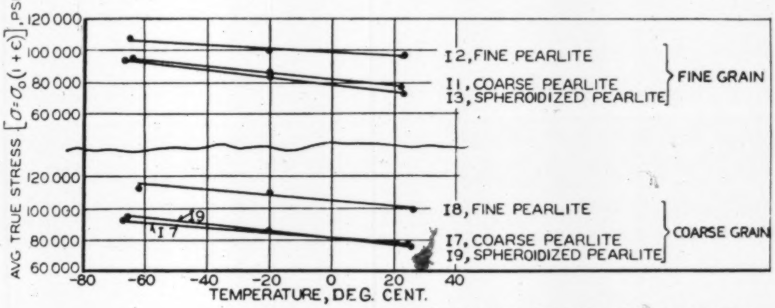


BOTH "I" AND "J" AS SUPPLIED WERE OPEN HEARTH, MEDIUM-CARBON STEELS. "I" HAD GRADUALLY COARSENING GRAIN (Si-KILLED), AND "J" ABRUPTLY COARSENING GRAIN CHARACTERISTICS (Si-Al KILLED)

(*b*) Grain Structure Comparison.

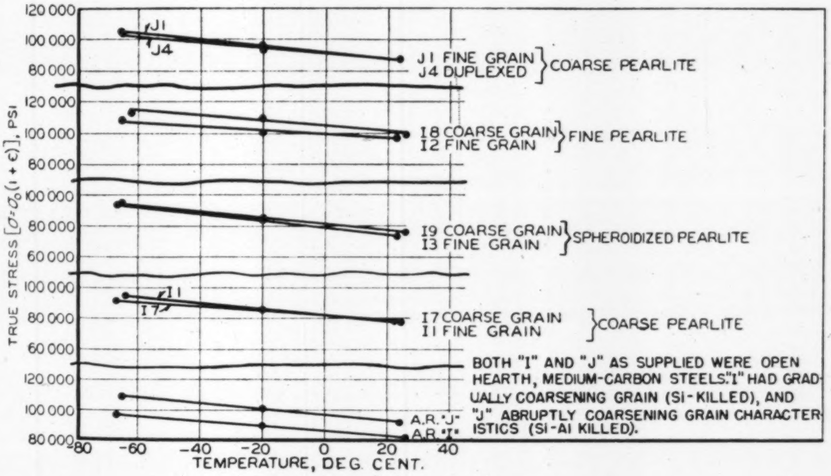
FIG. 10.—Pearlite and Grain Structure Comparison—Average True Stress at Fracture in Minimum Section of Neck as a Function of Temperature.

lowest ductility (the coarse pearlite), the finer-grained structure showed higher ductility at all temperatures. This was also true in the coarse pearlitic group made from the silicon-aluminum-killed steel.



MATERIAL AS SUPPLIED WAS AN OPEN HEARTH, MEDIUM-CARBON (0.26), AND SI-KILLED STEEL (GRADUALLY COARSENING GRAIN CHARACTERISTICS.)

(*a*) Pearlite Comparison.



BOTH "I" AND "J" AS SUPPLIED WERE OPEN HEARTH, MEDIUM-CARBON STEELS. "I" HAD GRADUALLY COARSENING GRAIN (SI-KILLED), AND "J" ABRUPTLY COARSENING GRAIN CHARACTERISTICS (SI-AI KILLED).

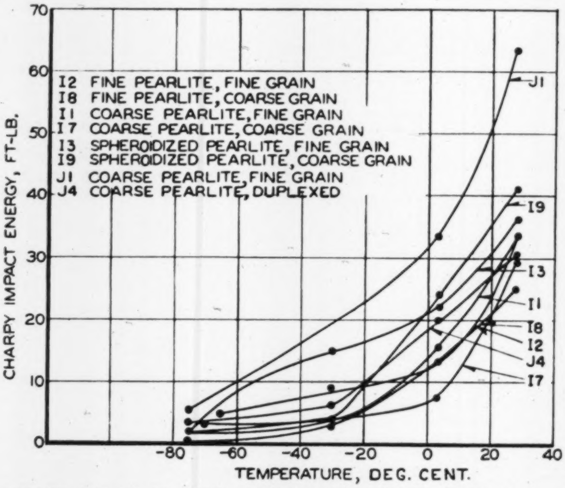
(*b*) Grain Structure Comparison.

FIG. 11.—Pearlite and Grain Structure Comparison—True Stress at Ultimate Load as function of Temperature.

A particular structure of silicon-killed steel showed higher values of strain at all temperatures of testing than did the similar structure made of silicon-aluminum-killed steel. The difference became more pronounced as the temperature dropped.

A general decrease in the strain value came about with a decrease in testing temperature from −20 to −65 C. for all structures. A change from ambient to −20 C. had little effect. The decrease in ductility due to temperature and material structure variations was accompanied by a transition from a ductile cup and cone to a brittle abrupt crystalline fracture.

From the foregoing it is obvious that for the best ductility at low temperatures, and for that matter at the higher temperatures too, a spheroidized pearlite structure is desirable. This reflects the necessity of tempering for low-temperature ductility. The fine grained-fine pearlite structure is next best. With the exception of the spheroidized pearlite, the fine-grained structure was superior in ductility. The superiority of the finer grain and finer pearlite reflects the necessity of controlling the heat-treating temperature and rate of cooling. A low temperature (no overheating) and a fast rate of cooling (oil quench), are desirable when tempering is not planned. Remarkable was the fact that, at −65 C., the coarse-grained-spheroidized pearlite of the silicon-killed steel showed almost three times the strain of the "duplex" grained-coarse pearlite of the silicon-aluminum-killed steel, the actual values being 1.88 and 0.70. The advantage of using the silicon-killed steel is somewhat lessened when one considers grain coarsening characteristics, since this type coarsens much easier and more throughout most of the heating range.



BOTH "I" AND "J" AS SUPPLIED WERE OPEN HEARTH, MEDIUM-CARBON STEELS. "I" HAD GRADUALLY COARSENING GRAIN (Si KILLED), AND "J" ABRUPTLY COARSENING GRAIN CHARACTERISTICS (Si-Al KILLED).

Fig. 12.—Impact Energy as Function of Temperature.

Figure 9 shows that the strain at the ultimate load presented a different picture when compared with the strain at fracture (Fig. 4). The coarse pearlite structures of both grain sizes in the silicon-killed steel showed the highest values at all temperatures. Next best was the spheroidized pearlite. In general the finer-grained structure was again the most ductile. The silicon-killed steel was the more ductile of the two again. The coarse-grained steels in general showed a decrease in strain with rising temperature of testing throughout the whole range. The strain for the fine-grained steels increased from −65 to −20 C., and then decreased from −20 C. to ambient temperature.

Aspects of Strength in Tension:

The strength of medium-carbon steel, as represented by the average true stress in the minimum section of the neck at fracture, was found greatest for the fine pearlite structures (see Fig. 10). Both the fine and coarse grained, made from the silicon-killed steel, showed the highest stress values of the structures tested at all temperatures. In this type pearlite, there was little difference due to grain-size variation. Next in strength were the spheroidized pearlite structures. They showed higher stress values than the coarse pearlite structures in both grain sizes and at all temperatures. In the spheroidized pearlite there was little difference due to grain-size variation. In the coarse pearlite group, however, the fine-grained structure showed the higher value of stress at all temperatures. The superiority of the fine grain was also true for the coarse pearlitic group of the silicon-aluminum-killed steel.

It was found that a particular structure of the silicon-aluminum-killed steel was stronger at all temperatures than the corresponding structure made from silicon-killed steel. The difference was practically the same at any temperature. This was the reverse of what was found in the ductility considerations, where the silicon-killed steel was superior.

Throughout the whole testing range, a decrease in temperature brought about an increase in fracture stress for all structures.

The foregoing statements of the advantage of the fine pearlite in strength at all temperatures indicates again, as in the ductility, the importance of a fast cooling rate (oil quench). The fineness of grain, as long as the structure was an oil-quenched product, was unimportant in the strength property. Remarkable was the great difference in fracture stress, at all temperatures, between the fine grained-fine pearlite and coarse grained-coarse pearlite specimens, the values being 171,500 psi. for the former and 114,000 psi. for the latter at −65 C. Since the silicon-aluminum-killed steel showed stronger structures for those comparisons made, it is believed that a fine grained-fine pearlite in this steel, if tested, would have surpassed the values obtained for the same structure in the silicon-killed steel.

Somewhat similar effects occurred in the true stress at the ultimate load. Figure 11 brings out that the fine pearlite again showed the highest values at all temperatures. No large differences were noted in the other two types of pearlite. The grain size was important only in the fine pearlite group, where slightly higher stress values occurred at all temperatures for the coarse grained samples. The superiority of the silicon-aluminum-killed steel was again evident in the structures compared, at all temperatures. As in the case of the fracture stress, decreasing the temperature resulted in a general increase of the stress at the ultimate load for all structures of both steels.

Aspects of Strength in Impact:

The advantages of having a silicon-aluminum-killed steel for strength in impact at any temperature was brought out in the Charpy tests (see Fig. 12). Within the silicon-killed group the fine-grained-spheroidized and fine pearlite were strongest at the lower temperatures. The tests showed the importance of having a fine grain and fine pearlite for strength in impact at low temperatures. The extreme drop in impact energy with a decrease in temperature was noted for all structures. This was accompanied by the transition from a ductile fibrous to a brittle abrupt crystalline fracture.

The spheroidized pearlite of the silicon-killed steel showed advantages in impact strength over the other structures of this steel at the higher temperatures. The fineness of grain was important at the higher temperatures also.

Acknowledgment:

Acknowledgments are due to A. Nadai of the Westinghouse Research Laboratories for his guidance in this work, and to F. C. Hull, R. L. Anderson, and E. K. Hann, also of the Westinghouse Research Laboratories, for their advice and help in the metallurgical problems involved. Permission to publish the test results was obtained from the David Taylor Model Basin.

THE INFLUENCE OF CONDITIONS OF HEAT TREATMENT AND HOT-COLD WORK ON THE PROPERTIES OF LOW-CARBON N-155 ALLOY AT ROOM TEMPERATURE AND 1200 F.*

By J. W. Freeman,[1] E. E. Reynolds,[1] D. N. Frey,[2] and A. E. White[1]

Synopsis

The effects of systematic variation of solution treatments, aging treatments, and hot-cold work on bar stock from one heat of low-carbon N-155 alloy were evaluated by means of physical properties at room temperature and rupture tests at 1200 F. The range in yield strength at 0.02 per cent offset at room temperature was from 30,000 to 134,000 psi. Rupture strengths varied from 40,000 to 66,000 psi. at 100 hr. and from 35,000 to 56,000 psi. at 1000 hr. The equivalent range in time for rupture under 40,000 psi. was from 100 hr. to an estimated 600,000 hr. for the same bar stock with different treatments. These ranges are greater than those resulting from wide variations in chemical composition and indicate the reason why it has not been possible to correlate composition of the chromium-nickel-cobalt alloys to properties at high temperatures.

Solution treatments alone resulted in the lowest strengths at room temperature and for rupture times up to several hundred hours. Proper aging slightly improved these properties but resulted in steeper stress-rupture-time curves so that the aged condition was the weakest at the longer time periods. Hot-cold work after the proper solution treatments produced the highest strength at both room temperature and at 1200 F.

The trends found for the various treatment conditions are believed to apply to other heats of low-carbon N-155 and for other alloys of the same type. It is expected, however, that other conditions of hot-working the the alloy would change the magnitude of the properties after most of the treatments. Other alloys will probably develop optimum properties from different conditions of treatment. The influence of the treatment conditions may not be the same for limited deformation by creep.

The two major variables which control the properties of alloys at high temperatures are chemical composition and prior treatment. Although prior treatment has at least as much effect as wide variations in chemical composition, there has been relatively little systematic study of its effects. Prior treatment is usually recognized only by reporting the history of making the alloys and by use of a "standard" heat treatment.

In recognition of the pronounced effect of prior treatment on the properties of the new heat-resistant alloys for gas turbines, an investigation of this effect is being sponsored by the National Advisory Committee for Aeronautics at the University of Michigan. This paper summarizes the first portion of this work (**1**).[3] Systematic variations of heat treatment and hot-cold work conditions were measured in terms of their effect on tensile properties at room temperature and rupture-test properties at 1200 F. of low-carbon N-155 alloy. The data thus far obtained are restricted to bar stock from one heat of the alloy.

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Low-carbon N-155 alloy is one of the outstanding alloys developed for use in gas turbines. It was known to have a wide range in properties depending on the conditions used in its production (**2, 3**). As far as could be ascertained it is reasonably representative of a number of so-called "superalloys" which do not show pronounced age hardening. For this reason it was selected as a suitable alloy for fundamental study of the effects of prior treatment.

The criteria of the effects of treatment conditions have been widely used in the experimental development of new alloys for gas turbines (**2**). The first evaluation of treatment conditions was therefore carried out on the same basis. The intent was to establish magnitudes of the effects and general trends. These are being used to guide fundamental research on the cause of the effects. The trends should reduce the amount of testing required to obtain quantitative rules for controlling the effects in low-carbon N-155 and other similar alloys.

TEST MATERIAL

The producer of the low-carbon N-155 alloy used in this investigation furnished the following data regarding its chemical composition:

ELEMENT	PER CENT	ELEMENT	PER CENT
Carbon	0.12	Columbium	1.10
Chromium	21.33	Manganese	1.64
Nickel	18.88	Silicon	0.39
Cobalt	18.60	Nitrogen	0.12
Molybdenum	3.21	Sulfur	0.003
Tungsten	1.97	Phosphorus	0.026

Fabrication Procedure:

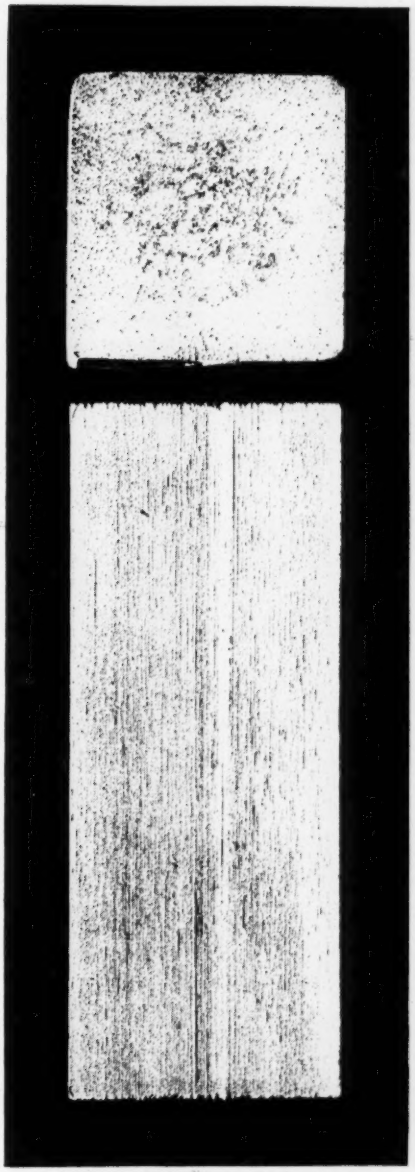

FIG. 1.—Macrostructures of Original Hot-Rolled Bar Stock of Low-Carbon N-155 Alloy. Etched 2 hr. in Marble's Reagent at 160 F. plus 15 min. in aqua regia in glycerine at 120 F.

The approximately 600-lb. (8 by 7 in.) ingot was hammer-cogged to 2-in. square billets with 2050 F. as maximum and

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[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 645.

TABLE I.—ROOM-TEMPERATURE PHYSICAL PROPERTIES OF LOW-CARBON N-155 BAR STOCK.

Heat Treatment					Hot Cold Rolling[d]		Brinell Hardness	Room Temperature Tensile Properties						
Solution Treatment			Aging Treatment[b]					Tensile Strength, psi.	Offset Yield Strength, psi.			Proportional Limit, psi.	Elongation in 2 in., per cent	Reduction of Area, per cent
Temperature, deg. Fahr.	Time, hr.	Method of Cooling[a]	Temperature, deg. Fahr.	Time, hr.	Temperature, deg. Fahr.	Per cent Reduction			0.02 per cent	0.1 per cent	0.2 per cent			
AGING AND ROLLING HOT-ROLLED BAR STOCK.														
As hot rolled			....	..	...	..	233	128 500	72 500	76 500	78 500	57 500	40.5	55.7
....	.	....	1350	24	...	..	214	124 500	52 700	62 500	66 300	37 500	36	38.2
....	.	....	1500	24	....		212	124 000	46 500	58 000	62 500	32 500	36	40.3
....	.	....	1750	24	....	..	210	119 625	44 500	55 100	59 000	30 000	39	42.8
....	.	....	....	..	75	10	307	145 750	99 500	123 200	128 700	57 500	31	53.0
....	.	....	....	..	1200	5	271	137 700	87 500	99 000	103 000	75 000	31.5	48.7
....	.	....	....	..	1200	10	312	146 750	98 500	118 000	121 000	70 000	25.5	47.0
....	.	....	....	..	1200	15	328	156 700	121 500	135 500	140 000	82 500	22	43.3
....	.	....	1400[c]	24	1200	15	311	142 250	96 000	108 000	112 000	77 500	25	42.1
....	.	....	....	..	1200	20	323	162 500	134 000	145 000	148 500	112 500	19	40.7
20 per cent reduction at 1200 F. + 65 per cent reduction from 1800 F. to 1400 F.							305							
(1800 F. 2 hr. A C. to 1400 F. + 20 percent reduction at 1400 F.)—repeated five more times + 1800 F. 2 hr. A.C.							189							
SOLUTION TREATED AT 1800 F.														
1800	2	W.Q.	....	..	....	..	207	122 875	50 000	57 500	62 000	30 000	39	46.8
1800	2	W.Q.	....	..	1200	15	290	145 000	104 000	122 500	127 000	80 000	24.5	42.7
SOLUTION TREATED AT 1950 F.														
1950	2	W.Q.	....	..	....	..	198	120 250	50 000	57 000	61 000	40 000	49	64.8
1950	2	W.Q.	....	..	1200	15	274	148 250	109 000	125 000	129 000	70 000	26	52.5
SOLUTION TREATED AT 2050 F. (A) Time and cooling rate														
2050	1	W.Q.	....	..	....	..	192	119 750	44 500	54 500	58 500	32 500	50	63.9
2050	2	W.Q.	....	..	....	..	208	117 500	47 000	56 000	58 500	27 500	44	62.4
2050	2	A.C.	....	..	....	..	189	119 800	44 500	52 500	56 500	35 000	56	63.7
2050	5	W.Q.	....	..	....	..	189	118 450	48 000	57 000	59 000	37 500	52	64.8
(B) Aging time and temperature														
2050	2	W.Q.	1400	2	....	..	190	119 750	45 500	57 500	61 000	37 000	42.5	51.0
2050	2	W.Q.	1400	8	....	..	179							
2050	2	W.Q.	1400	16	....	..	183							
2050	2	W.Q.	1400	24	....	..	220	118 500	38 000	53 000	58 500	17 500	36	41.6
2050	2	W.Q	1400	50	....	..	206							
2050	2	W.Q.	1350	24	....	..	190	119 625	48 500	56 400	60 000	37 500	42	50.0
2050	2	W.Q.	1500	24	....	..	213	120 750	50 000	57 000	60 500	37 500	38	41.2
2050	2	W.Q.	1600	24	....	..	209	116 150	30 000	49 500	54 000	22 500	35	39.9
2050	2	W.Q.	1750	24	....	..	185	114 900	42 000	49 500	53 000	32 500	29.5	43.9
(C) Cold-working amount and temperature														
2050	2	W.Q.	....	..	75	10	296	136 100	97 250	112 800	117 000	62 500	36	60.7
2050	2	W.Q	....	..	1200	5	249	125 500	67 000	81 000	84 000	42 500	35.5	54.7
2050	2	W.Q.	....	..	1200	10	301	138 750	90 000	107 500	112 000	52 500	28	49.2
2050	2	W.Q.	1400	24	1200	10	287	134 000	90 000	105 000	109 000	65 000	23.5	37.9
2050	2	W.Q.	....	..	1200	15	296	145 500	110 500	120 500	124 500	65 000	26	53.2
2050	2	W.Q.	1400[c]	24	1200	15	262	138 250	94 500	106 500	111 000	75 000	23.5	37.5
2050	2	W.Q.	....	..	1200	20	340	154 500	121 000	134 000	138 000	85 000	23.5	49.5
							301	151 000	104 000	124 500	131 000	65 000	24	49.0
2050	2	W.Q.	....	..	1200	25	318	156 000	104 000	130 000	137 500	70 000	22	48.1
2050	2	W.Q.	....	..	1000	15	297	145 750	100 000	116 500	122 000	77 500	26.5	51.9
2050	2	W.Q.	....	..	1400	15	290	141 000	95 500	110 500	116 000	77 500	25	45.7
2050	2	W.Q.	....	..	1600	15	252	128 250	83 000	92 000	96 000	62 500	29	45.1
2050	2	W.Q.	....	..	1700	15	255	128 750	81 000	90 200	93 700	57 500	32.5	48.6
2050	2	W.Q.	....	..	1800	15	250	129 300	78 000	87 400	91 000	57 500	38	46.8
SOLUTION-TREATED AT 2100 F.														
2100	1	W.Q.	....	..	....	..	197	117 250	38 500	52 000	57 000	17 500	47	63.2

TABLE I.—*Concluded.*

Heat Treatment					Hot Cold Rolling[d]		Brinell Hardness	Room Temperature Tensile Properties						
Solution Treatment			Aging Treatment[b]						Offset Yield Strength, psi.					
Temperature, deg. Fahr.	Time, hr.	Method of Cooling[a]	Temperature, deg. Fahr.	Time, hr.	Temperature, deg. Fahr.	Per cent Reduction		Tensile Strength, psi.	0.02 per cent	0.1 per cent	0.2 per cent	Proportional Limit, psi.	Elongation in 2 in., per cent	Reduction of Area, per cent
SOLUTION-TREATED AT 2150 F.														
2150	1	W.Q.	....	..	....	..	193	116 250	30 000	47 000	53 000	10 000	45.5	62.2
SOLUTION TREATED AT 2200 F. (A) Time and cooling rate														
2200	0.5	W Q.	....	..	....	..	180	118 300	48 000	54 500	58 000	40 000	54	64.8
2200	1	W.Q.	....	..	....	..	205	115 750	42 000	53 000	57 000	25 000	46.5	64.3
2200	1	A.C.	....	..	....	..	175	118 250	42 000	48 500	52 000	30 000	54	64.6
(B) Aging time and temperature														
2200	1	W.Q.	1400	2	....	..	192	117 250	47 000	57 000	61 000	40 000	42	42.4
2200	1	W Q.	1400	8	....	..	185							
2200	1	W.Q.	1400	16	....	..	190							
2200	1	W.Q.	1400	24	....	..	221	119 250	48 000	61 000	65 000	25 000	32	39.8
2200	1	W.Q.	1400	50	....	..	196							
2200	1	W Q.	1350	24	....	..	205	120 125	54 000	61 000	64 000	45 000	38.5	40.9
2200	1	W.Q.	1350	50	....	..	213	118 000	50 000	57 500	60 000	32 500	36	41.9
2200	1	W.Q.	1500	24	....	..	202	121 750	50 000	58 500	63 500	40 000	36.5	40.3
2200	1	W Q.	1600	24	....	..	212	118 250	42 500	53 000	57 500	22 500	31.5	34.3
2200	1	W Q.	1750	24	....	..	195	115 250	43 000	50 000	53 500	30 000	39	32.4
(C) Cold working amount and temperature														
2200	1	W.Q.	....	..	1200	5	224	122 500	65 000	76 500	80 000	42 500	40	59.5
2200	1	W.Q.	....	..	1200	10	256	132 000	90 000	99 000	102 000	77 500	33.5	55.8
							289	136 500	90 000	102 500	107 000	75 000	31.5	55.7
2200	1	W.Q	1400	24	1200	10	288	136 250	98 500	107 500	111 000	70 000	22.5	34.7
2200	1	W.Q.	..		1200	15	289	142 000	97 000	112 000	117 000	72 500	28	52.1
2200	1	W Q.	1400[c]	24	1200	15	293	142 000	103 000	115 000	118 500	85 000	24	37.8
2200	1	W Q.	....	..	1000	15	294	145 500	105 000	119 000	123 000	80 000	27.5	56.0
2200	1	W.Q.	....	..	1400	15	289	140 500	94 000	111 000	116 000	67 500	26.5	46.2
2200	1	W Q.	....	..	1600	15	249	128 500	80 000	92 000	96 000	62 500	26	40.7
SOLUTION TREATED AT 2250 F.														
2250	0.5	W.Q.	....	..	....	..	178	116 000	44 500	52 000	55 000	30 000	53	64.1
SOLUTION TREATED AT 2300 F.														
2300	0.5	W.Q.	....	..	....	..	163	116 250	48 000	53 000	57 000	40 000	56.5	65.8

[a] W.Q. = water-quenched; A.C. = air-cooled.
[b] All aging treatments preceded hot-cold rolling except where noted.
[c] Aged after rolling.
[d] All hot-cold rolled material was given a final stress relief at 1200 F. for 1 hr.

1750 F. as minimum working temperatures. The 2 in.-square billets were hot-rolled to ⅞-in. square bars in one heat from 2075 F. to a finishing temperature of 1725 F.

Structure:

As received, the bar stock had a Brinell hardness of 233 and a 0.02 per cent offset yield strength of 72,500 psi. at room temperature. The grain size was finer than 8 and there was relatively little grain boundary precipitation, as is shown by Fig. 6. Considerable center segregation of excess constituents was observed as is shown by the macrographs in Fig. 1. It was decided that the segregated condition was not too severe and that the stock was typical of the material.

EXPERIMENTAL PROCEDURE

The experimental procedure was designed to show the effects of the following conditions of treatment on the properties of low-carbon N-155 alloy at room temperature and the rupture-test characteristics at 1200 F.:

Hot-rolled stock:

1. Aging.
2. Hot-cold work.
3. Agglomeration of excess constituents.

Solution-treated stock:

1. Temperature of solution treating.
2. Time of solution treatment and cooling rate.
3. Temperature of aging.
4. Time of aging.
5. Hot-cold work after various solution treatments.
6. Temperature of hot-cold working.
7. Amount of hot-cold work.
8. Aging prior to hot-cold work.
9. Aging after hot-cold work.

A diagram which shows all the 67 treatments used is given in Fig. 2.

The individual treatments were made on bars 8½ in. long cut from ⅞-in. square stock. Solution treatments were carried out in a gas-fired furnace. Aging was done in an electric resistance furnace. Hot-cold working was accomplished by rolling in a 5-in., 2-high rolling mill using the following general procedure:

A bar was heated for 1 hr. at a temperature 20 F. higher than the desired rolling temperature. In two passes the bar was reduced 10 per cent. Reductions of 5 and 10 per cent were made with no reheat, 15 and 20 per cent with one reheat, and 25 per cent with two reheats. A reheat consisted of placing the partially-rolled bar in the furnace to bring it back to 20 F. above rolling temperature. All hot-cold rolled bars were given a final stress relief of 1 hr. at 1200 F.

The treated bars were sectioned to give a 5½ in. long by 0.505-in. diameter ten-

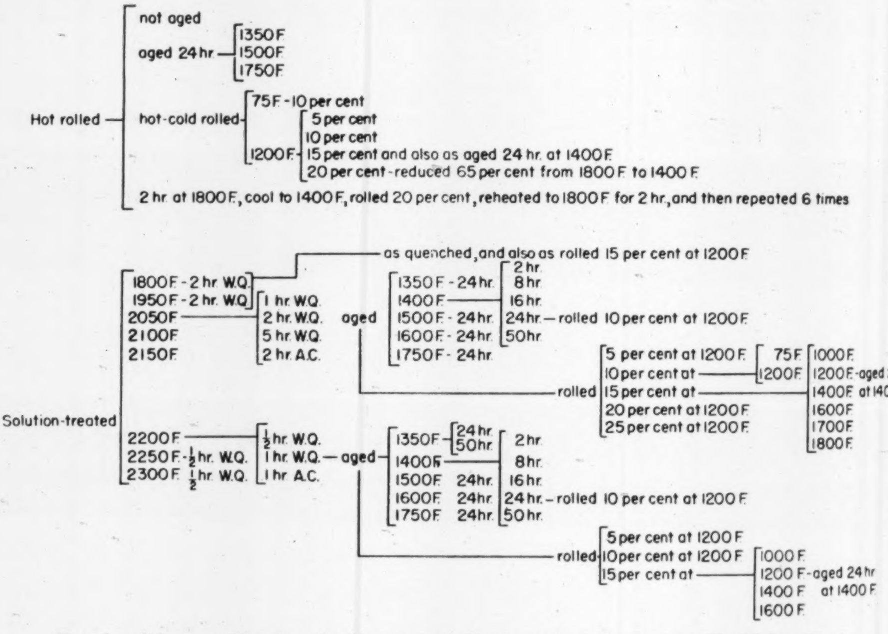

Hot rolled
not aged
aged 24 hr
1350 F
1500 F
1750 F
hot-cold rolled
75 F - 10 per cent
1200 F
5 per cent
10 per cent
15 per cent and also as aged 24 hr. at 1400 F
20 per cent - reduced 65 per cent from 1800 F to 1400 F
2 hr. at 1800 F, cool to 1400 F, rolled 20 per cent, reheated to 1800 F for 2 hr., and then repeated 6 times
Solution-treated
1800 F - 2 hr. W.Q.
1950 F - 2 hr. W.Q.
2050 F
2100 F
2150 F
as quenched, and also as rolled 15 per cent at 1200 F
1 hr. W.Q.
2 hr. W.Q.
5 hr. W.Q.
2 hr. A.C.
aged
1350 F - 24 hr.
1400 F
1500 F - 24 hr.
1600 F - 24 hr.
1750 F - 24 hr.
2 hr.
8 hr.
16 hr.
24 hr. - rolled 10 per cent at 1200 F
50 hr.
rolled
5 per cent at 1200 F
10 per cent at
15 per cent at
20 per cent at 1200 F
25 per cent at 1200 F
75 F
1200 F
1000 F
1200 F - aged 24 at 1400 F
1400 F
1600 F
1700 F
1800 F
2200 F
2250 F - ½ hr. W.Q.
2300 F ½ hr. W.Q.
½ hr. W.Q.
1 hr. W.Q.
1 hr. A.C.
aged
1350 F
24 hr.
50 hr.
1400 F
1500 F 24 hr.
1600 F 24 hr.
1750 F 24 hr.
2 hr.
8 hr.
16 hr.
24 hr. - rolled 10 per cent at 1200 F
50 hr.
rolled
5 per cent at 1200 F
10 per cent at 1200 F
15 per cent at
1000 F
1200 F - aged 24 hr at 1400 F
1400 F
1600 F

FIG. 2.—Diagram Showing the Treatments Used on the Low-Carbon N-155 Bar Stock.

TABLE II.—RUPTURE TEST CHARACTERISTICS AT 1200 F. OF LOW-CARBON N-155 BAR STOCK.

Heat Treatment					Hot-Cold Rolling[d]		1200 F. Rupture Properties					
Solution Treatment			Aging Treatment[b]									
Temperature, deg. Fahr.	Time, hr.	Method of Cooling[a]	Temperature, deg. Fahr.	Time, hr.	Temperature, deg. Fahr.	Per cent Reduction	Stress, psi.	Rupture Time, hr.	Elongation in 1 in., per cent	Reduction of Area, per cent	Rupture Strength, psi.	
											100 hr.	1000 hr.
AGING AND ROLLING HOT-ROLLED BAR STOCK.												
As hot rolled							55 000 50 000 45 000 40 000	8.5 75 252 610	9.5[e] 17 19 34	8.5 23.3 23.3 48.3	49 500	37 500
....		....	1350	24	....	....	50 000 45 000 41 000	123 241 411	12 38 33	49.2 55.3 55.3	51 000	35 500
....	.	....	1500	24	....	....	50 000 45 000 40 000	54 166 430	16 12 40	46.5 50.1 58.6	47 000	36 000
....	.	....	1750	24	....	....	50 000 45 000 40 000	40 101 430	49 38 36	51.9 44.7 53	45 000	37 000
....		....	....	....	75	10 (9.8)	60 000 55 000 50 000	73 230 809	4 13 10	4.0 32.4 16.7	58 500	49 000
....	.	....	....	....	1200	5 (4.5)	60 000 55 000 50 000	48 216 387	8 8 12	22.2 32.2 36.0	56 000	46 000[b]
....		....	....	....	1200	10	65 000 60 000 55 000 50 000	36 115 302 528	5 16[e] 16 15	12.5 28.8 38.8 40.8	61 000	47 000
....		....	....	....	1200	15 (14.1)	60 000 55 000 50 000	157 325 845	6 8 6.5	20.6 24.1 17.9	63 000	49 000
....	.	....	1400[c]	24	1200	15 (15.6)	55 000 52 500 50 000	72 108 364	16 27 19	51.9 40.8 38.8	53 000	47 000
....	.	....	....	....	1200	20	65 000 60 000 55 000 50 000	84 112 210 536	10 10 18 15	21.8 23.3 44.7 33.5	62 000	46 000
20 per cent reduction at 1200 F. + 65 per cent reduction from 1800 F. to 1400 F.							60 000 50 000 40 000 36 000	25 85 429 785	30 26 16 12	50.4 36.6 24.8 19.0	49 000	35 000
(1800 F. for 2 hr. A.C. to 1400 F. + 20 per cent reduction at 1400 F.)—repeated five more times + 1800 F. for 2 hr. A.C.							50 000 40 000 44 000 35 000	23 240 163 1086	36 34 35 28	41.1 44.6 41.5 35.6	43 500	35 000
SOLUTION TREATED AT 1800 F.												
1800	2	W.Q.	....	..	....	....	45 000 40 000 39 700 35 000	51 120 175 1313	40 32 36 38	58.6 56.1 55.3 52.0	42 000	35 000
1800	2	W.Q.	....	..	1200	15	55 000 50 000 45 000	103 241 415	13 9 14	41.5 32.8 46.0	55 000	40 000
SOLUTION TREATED AT 1950 F.												
1950	2	W.Q.	....	..	....	....	45 000 40 000 37 500	92 318 1107	27 25.5 30	35.0 40.8 40.8	45 000	38 000
1950	2	W.Q.	....	..	1200	15	64 000 60 000 55 000	59 168 517	4 5 5	8.1 17.2 16.3	61 000	52 000

Continued on pp. 624, 625, 626, and 627.

TABLE II.—*Continued.*

Heat treatment					Hot-Cold Rolling[d]		1200 F. Rupture Properties					
Solution Treatment			Aging Treatment[b]								Rupture Strength, psi.	
Temperature, deg. Fahr.	Time, hr.	Method of Cooling[a]	Temperature, deg. Fahr.	Time, hr.	Temperature, deg. Fahr.	Per cent Reduction	Stress, psi.	Rupture Time, hr.	Elongation in 1 in., per cent	Reduction of Area, per cent	100 hr.	1000 hr.
SOLUTION TESTED AT 2050 F. (A) Time and cooling rate												
2050	1	W.Q.	....	..	....	....	45 000	25	1[e]	17.8	45 000	40 000
							44 000	420	18	22.6		
							43 000	619	24	26.7		
							40 000	1138	17	15.6		
2050	2	W.Q.	....	..	....	....	48 000	33	3[e]	17.3	45 500	39 000
							45 000	180	10	18.9		
							40 000	687	19	23.3		
2050	2	A.C.	....	..	....	....	45 000	35	7.5[e]	14.4	43 000	39 000
							42 000	119	5	7.3		
							40 000	614	8.5[e]	17.8		
2050	5	W.Q.	....	..	....	....	51 000	62	..[e]	8.0	49 000	40 500
							48 000	181	12	12.5		
							45 000	141	10	10.9		
							40 000	1138	21	25.6		
(B) Aging time and temperature												
2050	2	W.Q.	1400	2	....	....	54 000	35	21	14.4	49 000	39 000
							50 000	116	11	18.9		
							45 000	163	12	10.9		
							40 000	825	17	20.4		
2050	2	W.Q.	1400	8	....	....	50 000	118	28	24.5	51 000	40 000
							45 000	310	24	23.3		
							40 000	954	29	35.8		
2050	2	W.Q.	1400	16	....	....	50 000	97	29	34.0	50 000	39 500
							45 000	300	27	40.8		
							40 000	860	30	41.2		
2050	2	W.Q.	1400	24	....	....	55 000	31	24	21.2	50 500	35 000
							50 000	123	38	33.0		
							45 000	205	37	36.9		
							40 000	436	44	44.7		
2050	2	W.Q.	1400	50	....	....	50 000	75	9	38.8	48 000	36 500
							45 000	300	33	37.9		
							42 500	285	37	40.8		
							40 000	423	5	25.6		
2050	2	W.Q.	1350	24	....	....	50 000	145	13	12.5	52 000	40 000
							45 000	343	12	21.0		
							40 000	1078	20	29.7		
2050	2	W.Q.	1500	24	....	....	50 000	87	40	36.9	48 000	36 000
							45 000	122	24	35		
							40 000	462	37	48.3		
2050	2	W.Q.	1600	24	....	....	50 000	74	40	41.8	47 500	35 000[f]
							45 000	132	31	43.7		
							40 000	361	38.5	45.8		
2050	2	W.Q.	1750	24	....	....	50 000	121	33	29.8	51 500	38 000
							45 000	306	39	52.8		
							39 000	659	36	53.0		
(C) Cold-working amount and temperature												
2050	2	W.Q.	....	..	75	10	60 000	24	1[e]	5.3	56 000	50 000
						(9.8)	55 000	275	4	11.2		
							50 000	1068	5	20.6		
2050	2	W.Q.	....	..	1200	5	55 000	46	2	5.6	52 000	44 000
							52 500	86	2	9.7		
							50 000	261	4[e]	8.5		
							45 000	821	18	23.3		

TABLE II—*Continued.*

Heat Treatment					Hot-Cold Rolling[d]		1200 F. Rupture Properties					
Solution Treatment			Aging Treatment[b]									
Temperature, deg. Fahr.	Time, hr.	Method of Cooling[a]	Temperature, deg. Fahr.	Time, hr.	Temperature, deg. Fahr.	Per cent Reduction	Stress, psi.	Rupture Time, hr.	Elongation in 1 in., per cent	Reduction of Area, per cent	Rupture Strength, psi. 100 hr.	Rupture Strength, psi. 1000 hr.
(C) Cold-working amount and temperature—*Continued*												
2050	2	W.Q.	....	..	1200	10	60 000	69	1[e]	2.7	59 000	52 000
							55 000	614	4	11.0		
							50 000	1465	8.5	23.2		
2050	2	W.Q.	1400	24	1200	10	55 000	88	22	39.8	54 000	43 500
							50 000	268	18	31.3		
							47 000	302	15[e]	23.3		
							44 000	920	15	40.0		
2050	2	W.Q.	....	..	1200	15 (14.3)	60 000	167	1	1.5	62 000	53 500
							55 000	389	8	21.0		
							52 000	1556	4	16.4		
2050	2	W.Q.	1400[c]	24	1200	15	55 000	110	18	37.9	55 500	48 000
							52 500	365	19	37.9		
							50 000	576	13.5	37.9		
2050	2	W.Q.	....	..	1200	20 (18.9)	63 000	102	1.5	2.8	62 000	56 000
							60 000	95	2	6.9		
							60 000	243	1.5	4.1		
							57 500	773	3	7.0		
							55 000	1348	3	7.8		
2050	2	W.Q.	....	..	1200	25	70 000	19	2	5.7	66 000	56 000
							65 000	200	4	11.0		
							60 000	493	5	18.9		
							55 000	1142	5	21.6		
2050	2	W.Q.	....	..	1000	15 (15 6)	65 000	79	2	2.5	63 500	53 000
							60 000	208	1.5	2 8		
							55 000	389	9	21.3		
							50 000	2087	4.5	19.1		
2050	2	W.Q.	....	..	1400	15 (15.3)	65 000	66	3	10.9	62 500	52 000
							60 000	176	3.5	13.2		
							55 000	551	6	25.6		
2050	2	W.Q	....	..	1600	15 (14.3)	60 000	40	15	29.8	56 000	45 000
							55 000	188	11	37.2		
							50 000	321	13	40.2		
							45 000	1013	14	29.5		
2050	2	W.Q.	....	..	1700	15 (15.7)	55 000	61	24.5	36.9	52 000	39 000
							50 000	123	25	36.9		
							45 000	342	28	39.8		
2050	2	W.Q.	....	..	1800	15 (15.0)	54 000	48.5	25	36.9	51 000	43 000
							50 000	125	19	35.0		
							45 000	535	20	33.0		
SOLUTION TREATED AT 2100 F.												
2100	1	W.Q.	....	..	....	....	50 000	35	9[e]	17.8	46 500	40 000
							45 000	140.5	6[e]	10.9		
							40 000	1003	16	17.8		
SOLUTION TREATED AT 2150 F.												
2150	1	W.Q.	....	..	....	....	45 000	83	5[d]	14.4	42 500	38 000
							41 000	47	5.5[d]	15.6		
							40 000	312	6.5[d]	9.7		
							37 000	1743	13	16.7		
SOLUTION TREATED AT 2200 F. (A) Time and cooling rate												
2200	½	W.Q.	....	..	....	....	45 000	14	8.5[e]	14.4	42 000	38 000
							42 500	149	7[e]	9.1		
							40 000	420	9[e]	6 2		

Continued on pp. 626 and 627.

TABLE II.—*Continued.*

Heat Treatment					Hot-Cold Rolling[d]		1200 F. Rupture Properties					
Solution Treatment			Aging Treatment[b]									
Temperature, deg. Fahr	Time, hr.	Method of Cooling[a]	Temperature, deg. Fahr.	Time, hr.	Temperature, deg. Fahr.	Per cent Reduction	Stress, psi.	Rupture Time, hr.	Elongation in 1 in., per cent	Reduction of Area, per cent	Rupture Strength, psi	
											100 hr	1000 hr.
SOLUTION TREATED AT 2200 F. (A) Time and cooling rate—*Continued*												
2200	1	W.Q.	....	..	....	....	50 000	4	5[e]	26.7	42 000	38 000
							45 000	29	4	15.6		
							40 000	247	6[e]	6.2		
							37 500	1500	....	....		
2200	1	A.C.	....	..	....	....	45 000	30	6	10.9	40 000	35 000[f]
							40 000	77	3[e]	9.7		
							37 000	396	5[e]	9.7		
(B) Aging time and temperature												
2200	1	W.Q.	1400	2	....	....	53 000	60	13	15.4	51 000	44 000
							50 000	113	15	13.3		
							45 000	658	14	20.0		
2200	1	W.Q.	1400	8	....	....	50 000	36	5	11.5	47 000	40 000
							45 000	178	8	7.3		
							42 000	558	8[e]	7.3		
2200	1	W.Q.	1400	16	....	....	50 000	67	12	17.8	48 500	41 000
							45 000	384	12[e]	16.5		
							42 000	510	15	17.8		
2200	1	W.Q.	1400	24	...	....	54 000	48.5	12[e]	18.3	50 000	42 000
							50 000	118	14	17.8		
							47 000	133	18	23.3		
							45 000	398	21	30.8		
2200	1	W.Q.	1400	50	....	....	50 000	88	20	33.0	49 000	38 500
							45 000	234	20	21.2		
							41 000	573	20	22.0		
2200	1	W.Q.	1350	24	....	....	50 000	170	15	23.3	53 000	39 500
							45 000	335	21	20.0		
							40 000	918	36	35.0		
2200	1	W.Q.	1350	50	....	....	50 000	53	12[e]	13.3	47 000	37 000
							45 000	145	10[e]	16.7		
							40 000	479	14[e]	21.2		
							35 000	3301	19	21.6		
2200	1	W.Q	1500	24	....	....	50 000	76	25	35.0	49 000	35 000
							45 000	209	22	25.6		
							40 000	346	30	39.6		
2200	1	W.Q.	1600	24	....	....	50 000	141	36	37.9	51 000	35 500
							45 000	216	32	36.0		
							40 000	468	35	43.8		
							35 000	1168	28	31.4		
2200	1	W.Q.	1750	24	....	....	50 000	78	30	39.8	49 000	40 000
							45 000	245	27.5	39.8		
							41 000	696	33	36.0		
(C) Cold-working amount and temperature												
2200	1	W.Q.	....	..	1200	5	55 000	76	1.5	7.0	54 000	47 000[f]
						(5.1)	50 000	333	2	12.2		
2200	1	W.Q.	....	..	1200	10	60 000	37	1.5	4.5	57 000	51 000
							50 000	1914	3.5	7.0		
2200	1	W.Q.	1400	24	1200	10	58 000	101	11	17.8	56 000	47 000[f]
							55 000	87	12[e]	14.4		
							52 500	200	10	14.4		
							50 000	403	15	24.5		

TABLE II.—*Continued.*

Heat Treatment					Hot-Cold Rolling[d]		1200 F. Rupture Properties				
Solution Treatment			Aging Treatment[b]								
										Rupture Strength, psi.	
Temperature, deg. Fahr.	Time, hr.	Method of Cooling[a]	Temperature, deg. Fahr.	Time, hr.	Temperature, deg. Fahr.	Per cent Reduction	Stress, psi.	Rupture Time, hr.	Elongation in 1 in., per cent	Reduction of Area, per cent	100 hr.	1000 hr.
(C) Cold-working amount and temperature—*Continued*												
2200	1	W.Q.	....	..	1200	15 (14.3)	55 000	12	1[e]	4.3	54 000[f]	52 000
							52 000	2115	2	6.0		
							45 000	Discontinued at 1943 hrs.				
2200	1	W.Q.	1400[c]	24	1200	15	65 000	78	4.5	10.9	64 000	53 500
							60 000	228	5.5	9.7		
							55 000	693	3[e]	5.0		
2200	1	W.Q.	....	..	1000	15 (15.6)	55 000	77	1.5	4.1	54 000	49 000
							52 500	134	0.5	1.7		
							50 000	574	1	1.5		
2200	1	W.Q.	....	..	1400	15 (14.9)	60 000	40	1	1.5	56 000	51 000
							55 000	146	1	4.2		
							52 500	581	1	1.4		
							50 000	1646	1.5	3.5		
2200	1	W.Q.	....	..	1600	15 (14.3)	55 000	110	4.5	13.8	55 500	43 500
							50 000	235	6.5	19.0		
							45 000	736	10	25.4		
SOLUTION TREATED AT 2250 F.												
2250	½	W.Q.	....	..	....	....	50 000	8.5	5[e]	16.5	41 000	38 000
							40 000	120	4	16.0		
							35 000	Discontinued at 2251 hr.				
							37 500	3122	10	15.3		
SOLUTION TREATED AT 2300 F.												
2300	½	W.Q.	....	..	....	....	45 000	98	6	12.8	44 000	37 500
							40 000	260	7[e]	7.7		
							36 000	Overheated at 1247 hr.				
							38 000	978	4.5	12.1		

[a] W.Q. = water-quenched, A.C. = air-cooled.
[b] All aging treatments preceded hot-cold rolling except where noted.
[c] Aged after rolling.
[d] All hot-cold rolled material was given a final stress-relief at 1200 F. for 1 hr.
[e] Fractured in gage mark.
[f] Estimated.

sion specimen from one end, four $2\frac{1}{2}$ in. long by 0.160-in. diameter rupture specimens from the other end, and hardness and metallographic specimens from the small piece of stock remaining.

The room-temperature tension tests were conducted in a 60,000-pound hydraulic testing machine. The modified-Marten's type extensometer system used had a sensitivity of 0.000003-in. per in.

Rupture tests were run in individual stationary units applying the stress through a simple beam and knife-edge system. Approximately 24 hr. was allowed for temperature adjustments prior to application of the stress. Only the minimum number of tests needed to indicate the 100- and 1000-hr. rupture strengths were run.

Brinell hardness tests were made on all the bars. Original metallographic samples were prepared for observation, and photomicrographs were made of representative samples.

RESULTS

Graphical summaries of the properties of most interest, based on the detailed test data of Tables I and II, show the effects of the various treatments. Analysis of the results is difficult because effects varied depending on the initial solution treatment conditions before aging and hot-cold work and on the rupture time period considered. The following observations only summarize trends, and exceptions for specific cases are numerous.

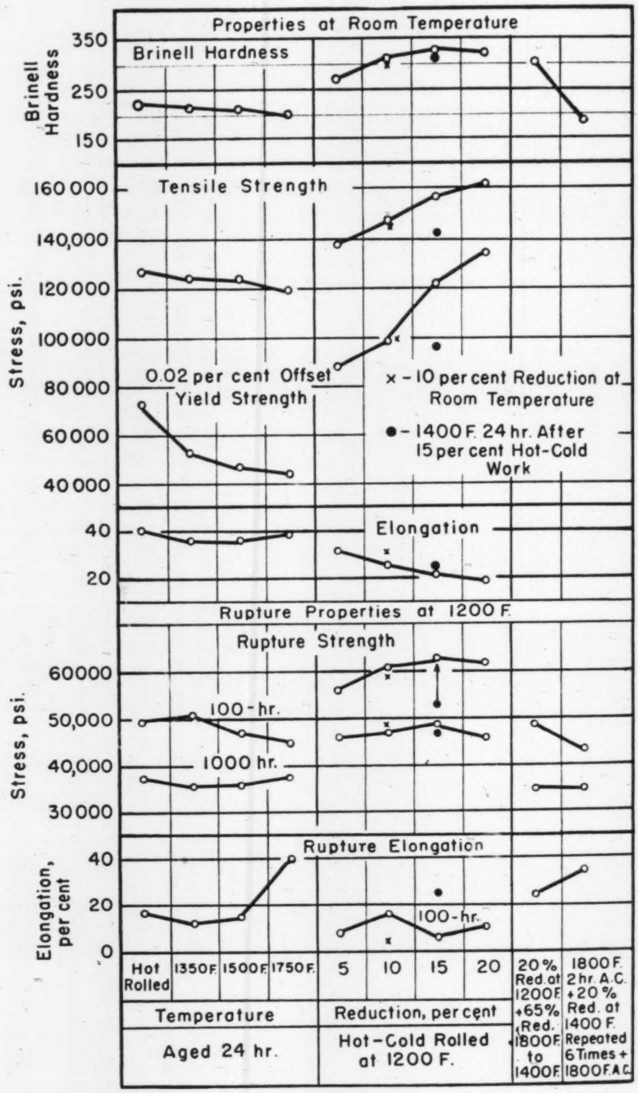


FIG. 3.—Effect of Aging and Rolling on the Properties of Hot-Rolled Bar Stock of Low-Carbon N-155 Alloy.

Hot-Rolled Stock:

The effects of aging and hot-cold working conditions are summarized in Fig. 3. The trends of the effects are covered in the following discussions. It should be recognized, however, that these trends

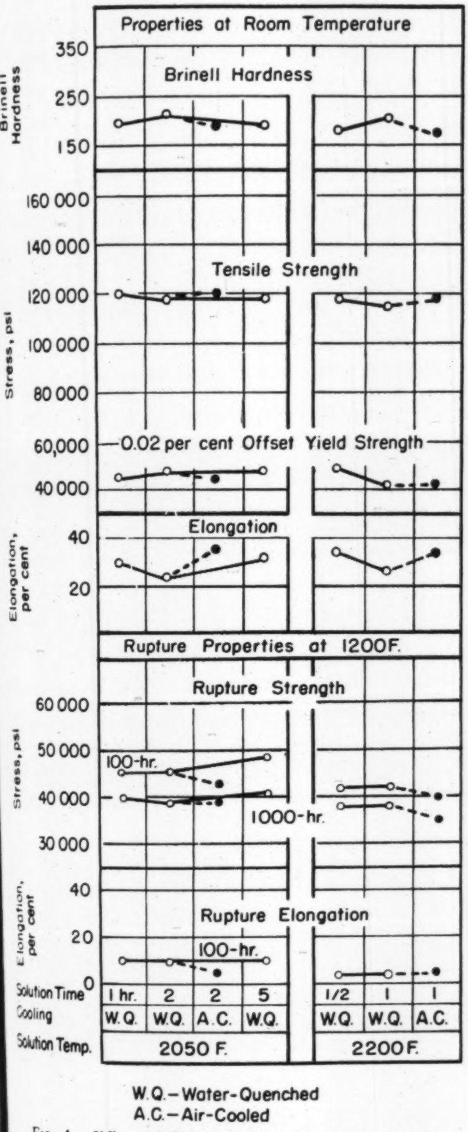


FIG. 4.—Effect of Time and Cooling Rate on the Properties of Solution Treated Bar Stock of Low-Carbon N-155 Alloy.

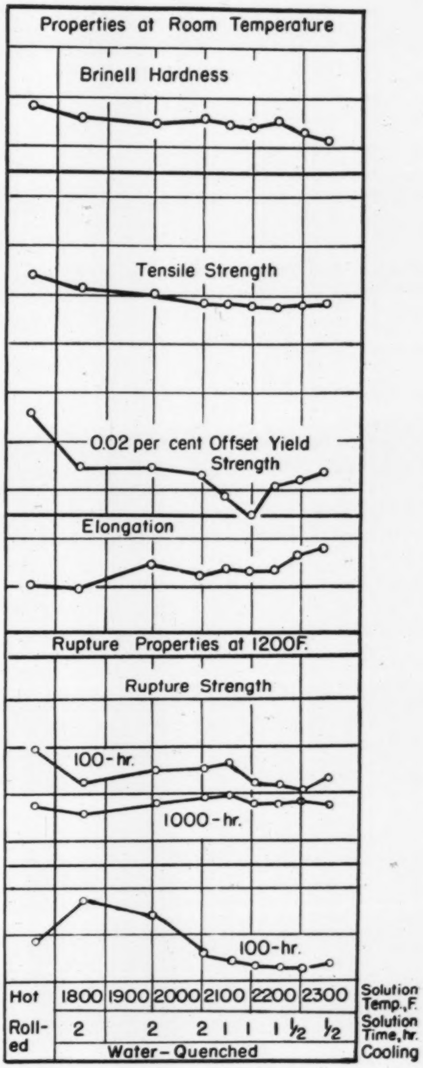
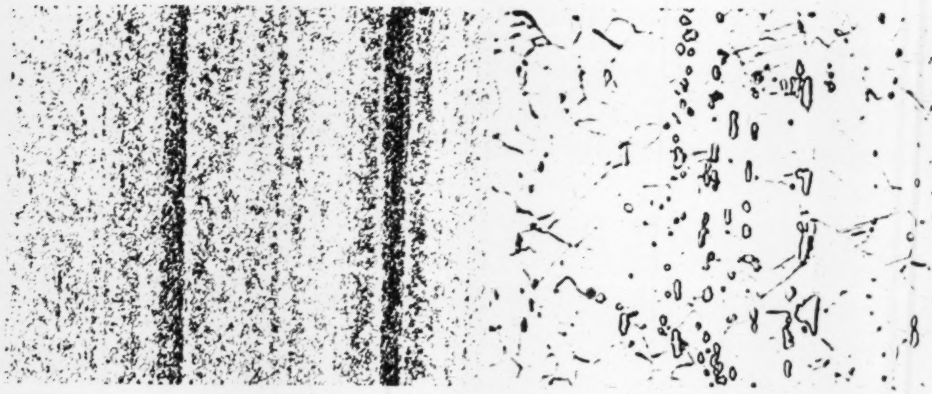
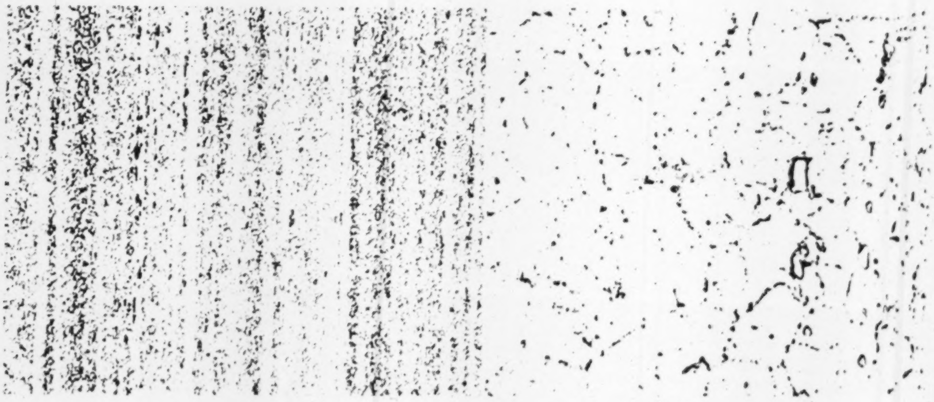


FIG. 5.—Effect of Solution Treating Temperature on the Properties of Low-Carbon N-155 Alloy Bar Stock.



× 100 × 1000

As Rolled



× 100 × 1000

1800 F., 2 hr.

FIG. 6.—Effect of Solution Treating Temperature on

NOTE.—All specimens were water-quenched from

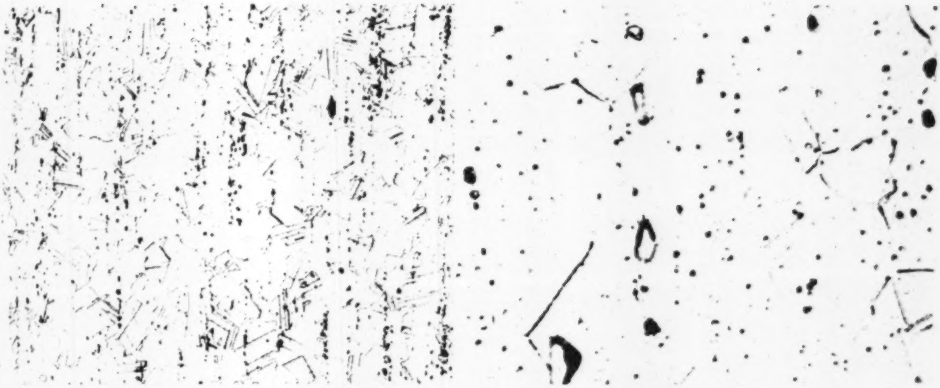
could be greatly modified by changing the initial hot-working conditions.

1. Increasing reduction of properties at room temperature, particularly yield strength, resulted from increasing temperature of aging the hot-rolled stock. Rupture properties were significantly affected only by aging at 1750 F. with a marked increase in elongation and some reduction in 100-hr. strength.

2. Hot-cold working at 1200 F. increased strength and hardness and reduced ductility at room temperature in proportion to the amount of reduction up to 20 per cent. Rupture strengths increased up to 15 per cent reduction only, with the major increases resulting from 5 to 10 per cent reduction only.

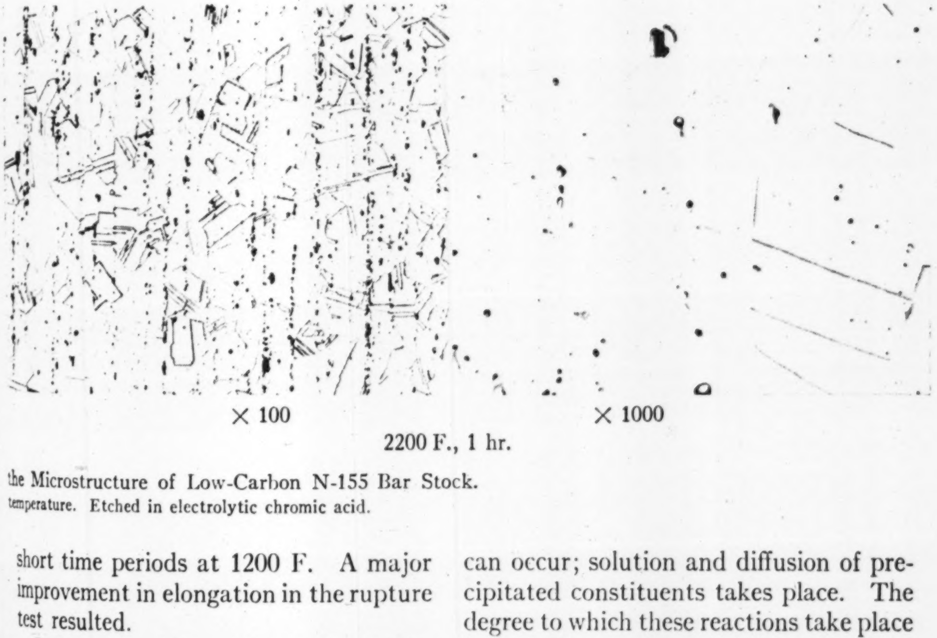
3. Reduced elongation in the rupture test was the only effect of reducing the hot-cold working temperatures for 10 per cent reduction from 1200 F. to room temperature.

4. Very limited data indicate that aging after hot-cold work sharply reduces strength at room temperature and for



× 100 × 1000

2050 F., 2 hr.



× 100 × 1000

2200 F., 1 hr.

the Microstructure of Low-Carbon N-155 Bar Stock.
temperature. Etched in electrolytic chromic acid.

short time periods at 1200 F. A major improvement in elongation in the rupture test resulted.

5. Severe working and annealing in the temperature range from 1800 to 1400 F. to precipitate and agglomerate excess constituents gave results similar to those resulting from aging at 1500 and 1750 F.

Solution Treatments:

Solution treatments involve several concurrent reactions in the metal. Cold work is annealed out; recrystallization can occur; solution and diffusion of precipitated constituents takes place. The degree to which these reactions take place is dependent on the solution-treating conditions and on the initial condition of the material before treatment. Prior treatment is now known to have a significant effect on the properties after treatments up to at least 2200 F. The trends shown by the following discussions of the data are therefore strictly only applicable to the particular stock tested. When the temperature of treatment was 2200 F. or higher the results are probably quite generally representative of the alloy.

1. Time of solution treatment at either 2050 or 2200 F. had little effect on properties, as Fig. 4 shows.

2. Air cooling tended to reduce rupture strengths in comparison to water quenching as indicated by the same figure.

3. The effects of solution-treating temperature on properties are summarized in Fig. 5. Strength and hardness at room temperature decreased with increasing temperature while ductility increased. Yield strengths were anomalous after heating at 2100 to 2200 F. The major effect on rupture properties was reduced elongation and reduction of short-time rupture strength. Increasing the temperature of solution treatment reduced the slope of the stress-rupture-time curves, thus indicating increased strength at prolonged time periods.

4. The reduction in elongation in the rupture test was accompanied by an increasing tendency for brittleness at the stress concentrations of the fillets and at gage marks of the specimens.

5. Typical microstructures resulting from the solution treatments are shown in Fig. 6. Partial grain growth started at 1950 F., and the grain size gradually increased with temperature of treatment. Grain size was not excessive after heating as high as 2300 F. It is, however, now known that prior treatment influences the grain size, in a manner not yet understood, even when the treatment temperature is 2200 F.

The structures indicated that a temperature of 2050 or 2100 F. was required to dissolve excess constituents precipitated during the heating-up period.

Aging after Solution Treatment:

1. The major effect of aging at 1350 to 1750 F. for 24 hr., as shown by Fig. 7, was to increase elongation in the rupture test and to widen the difference between rupture strengths at 100 and 1000 hr.

2. The effects of aging on properties seem rather slight in comparison to the effects on microstructure illustrated by Fig. 8. The indications are that grain boundary precipitation is connected with the increased rupture-test ductility.

3. Figure 9 shows that the changes that occur in rupture strength as a result of aging appeared after short aging times. There was little further change in 100-hr. strength after 2 hr. of aging at 1400 F. Increasing the aging time to 24 to 50 hr. tended to reduce rupture strengths slightly except for the 100-hr. strength after the 2200 F. solution treatment.

Elongation in the rupture test was increased by increasing time of aging except for the material solution treated at 2050 F. and aged for 50 hr. The increase in ductility was much greater in the material solution treated at 2050 F. than that treated at 2200 F. for aging time periods up to 24 hr.

There was very little difference between material aged at 1350 and 1400 F. for 24 and 50 hr.

Hot-Cold Work after Solution Treatment:

Prior heat treatment, temperature of hot-cold working, and degree of reduction were the major variables of hot-cold working conditions considered.

1. Prior solution treatment temperature had considerable effect on the properties after 15-per cent reduction at 1200 F., as is shown by Fig. 10. Increasing the solution temperature reduced strength at room temperature with little influence on ductility. Increasing the solution treating temperature tended to reduce 100-hr. strength and increase the 1000-hr. strength. An exception was that a treatment at 1800 F. sharply reduced all strength values after hot-cold work. Elongation in the rupture test was sharply reduced by increasing solution treatment temperature, and material treated at 2200 F. behaved in a very brittle manner.

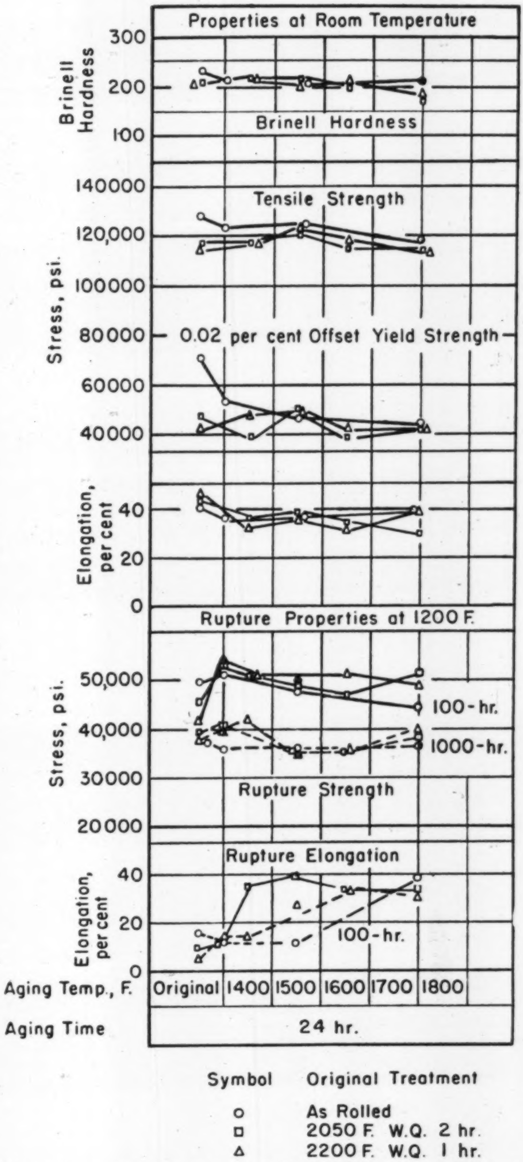
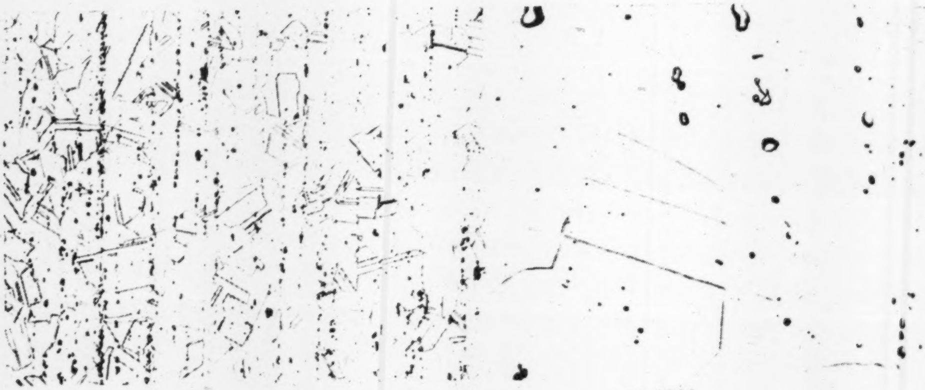
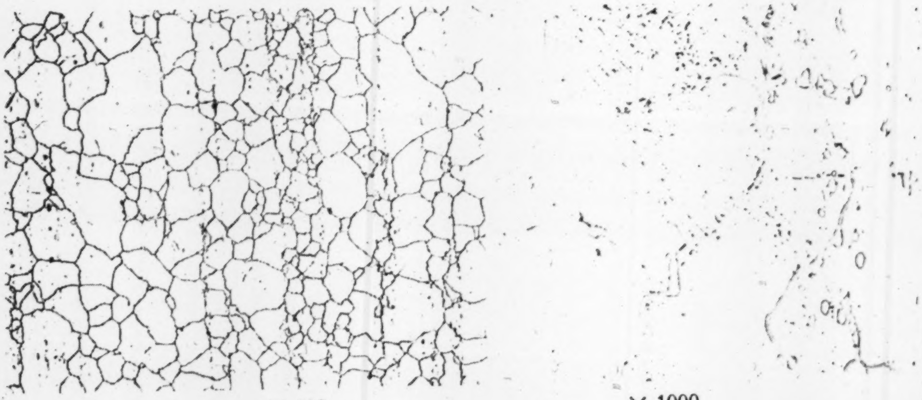


FIG. 7.—Effect of Aging at Various Temperatures on Bar Stock of Low-Carbon N-155 Alloy.



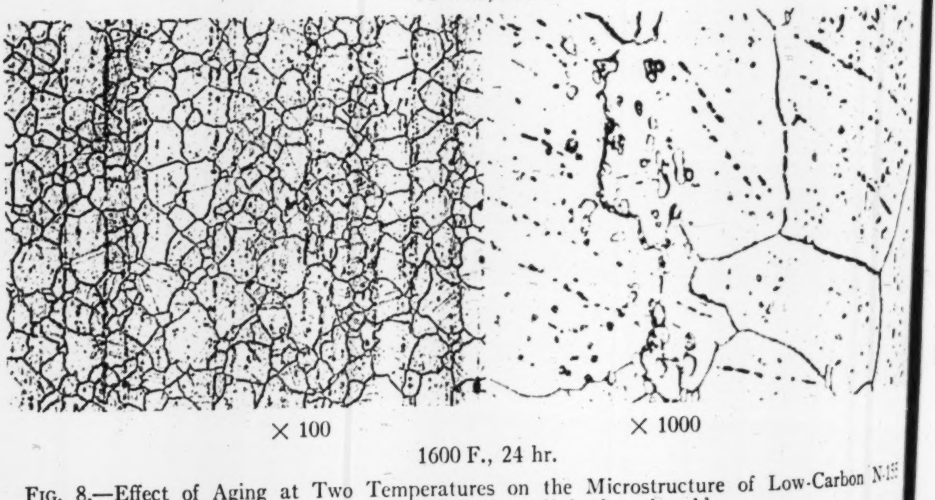
× 100 × 1000

Solution treated 2200 F., 1hr., water quenched.



× 100 × 1000

1400 F., 24 hr.



× 100 × 1000

1600 F., 24 hr.

FIG. 8.—Effect of Aging at Two Temperatures on the Microstructure of Low-Carbon N-155 Bar Stock. Etched in electrolytic chromic acid.

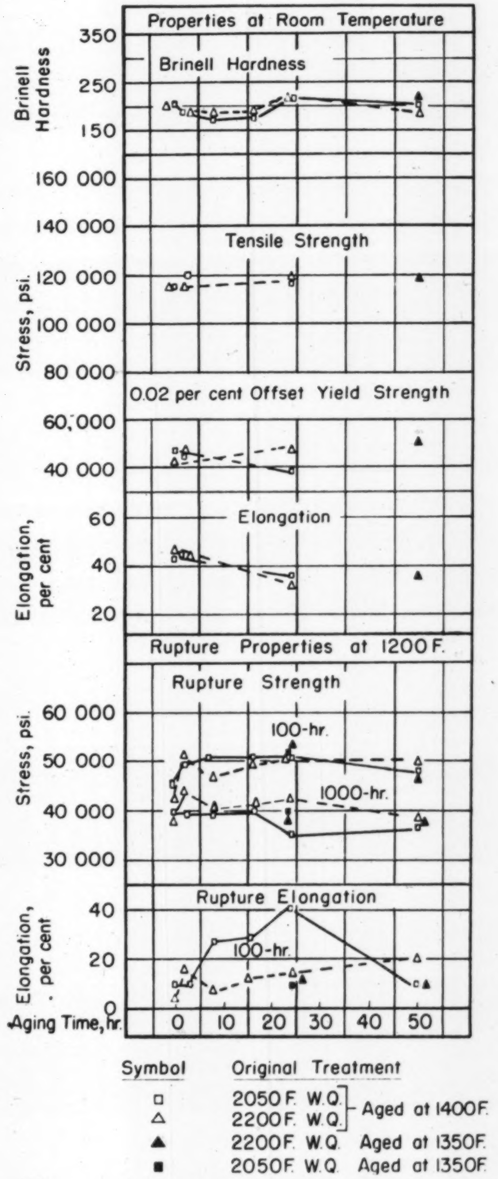
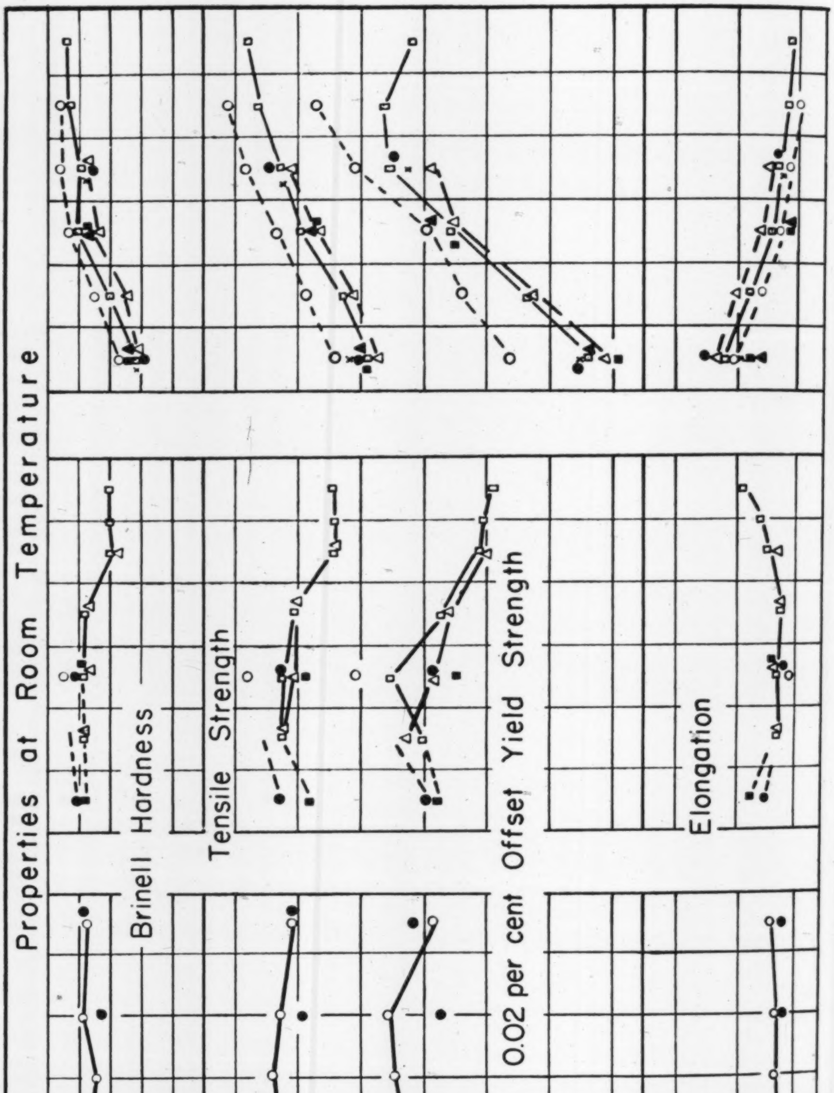


FIG. 9.—Effect of Aging Time on the Properties of Solution Treated Bar Stock of Low-Carbon N-155 Alloy.


Properties at Room Temperature
Brinell Hardness
Tensile Strength
0.02 per cent Offset Yield Strength
Elongation
Brinell Hardness
350
250
150
Stress, psi
160 000
140 000
120 000
100 000
80 000
60 000
40 000
Elongation, per cent
60
40
20

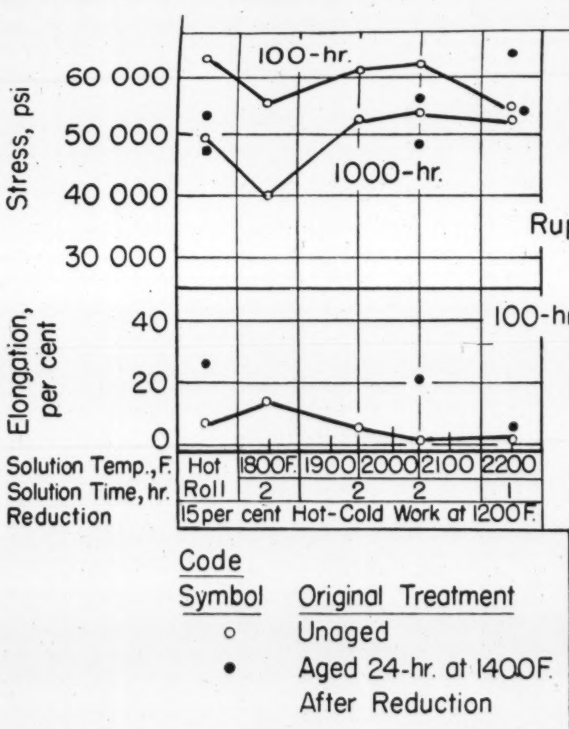


FIG. 10.—Effect of Prior Treatment on the Properties of 15 per cent Hot-Cold Worked Bar Stock of Low-Carbon N-155 Alloy.

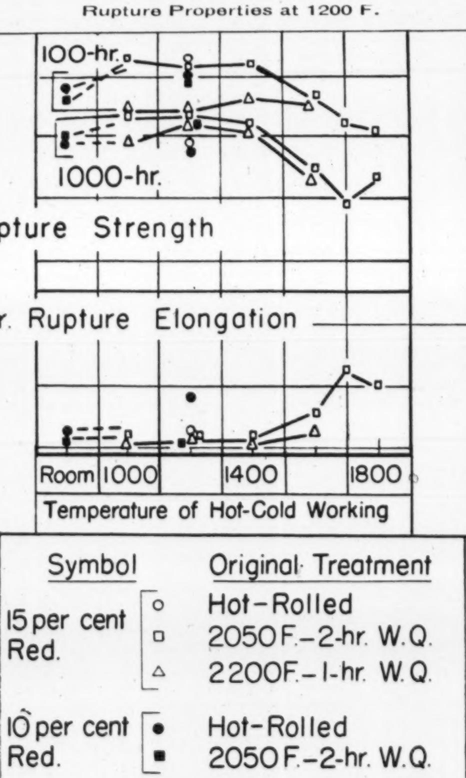


FIG. 11.—Effect of Hot-Cold Work at Various Temperatures on the Properties of Bar Stock of Low-Carbon N-155 Alloy.

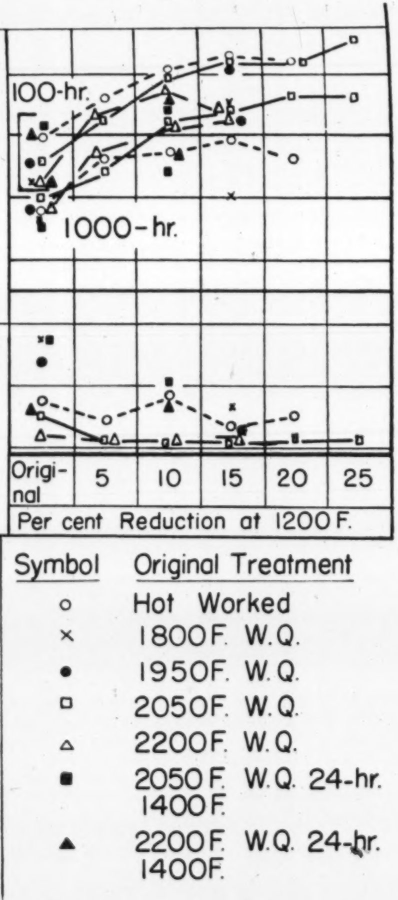


FIG. 12.—Effect of Hot-Cold Work at 1200 F. on the Properties of Bar Stock of Low-Carbon N-155 Alloy.

2. Figure 10 also shows that aging after hot-cold working resulted in decreased strength at both room temperature and 1200 F. except for the material solution treated at 2200 F. Rupture test ductility was markedly improved and the tendency for brittleness removed.

3. Strength at room temperature tended to fall off as the hot-cold working temperature was raised to 1400 F. and higher, as is shown by Fig. 11. Rupture properties were little effected until the temperature of hot-cold work was increased to 1600 and 1800 F. when the strength fell off and ductility increased.

The much smaller difference between rupture strengths at 100 and 1000 hr. (flatter stress-rupture-time curves) for the stock solution treated at 2200 F. prior to hot-cold work than for the stock treated at 2050 F. or left in the hot-rolled condition is emphasized by Fig. 11.

4. The effect of amount of reduction at 1200 F. is summarized by Fig. 12. Strength and hardness were increased and elongation reduced at room temperature in proportion to the amount of hot-cold work up to 25 per cent. There was some indication of a drop in yield strength after a solution treatment when the hot-cold work reduction was more than 20 per cent.

The curves of rupture strength *versus* degree of reduction tended to level off after 15 per cent reduction. Increasing the reduction tended to increase the difference between 100- and 1000-hr. strengths of the original hot-rolled stock. Material was not tested with more than 15 per cent reduction after a 2200 F. solution treatment due to excessive brittleness.

5. Figure 12 also shows that aging prior to hot-cold working reduced the resulting rupture strength and increased the elongation at 1200 F. Prior aging had little effect at room temperature except to reduce ductility.

6. The microstructures after hot-cold working did not reflect the pronounced changes in properties, as is indicated by Fig. 13.

DISCUSSION OF RESULTS

Probably the most important result from the investigation is that it emphasizes the degree to which the properties of an alloy of the type considered are dependent on conditions of prior treatment. The most severe limitation is the probability that the results are not generally applicable even to low-carbon N-155 alloy because original hot working conditions probably have a pronounced influence on the properties until solution treating temperatures are of the order of 2200 F. or higher. A further limitation is that high-temperature data are restricted to limited rupture testing at one temperature on one lot of stock. These considerations therefore serve to clarify the necessity for more research on the fundamental factors which control the properties of alloys of this type at high temperatures. Until this is done it will be necessary for users to design on the basis of excessively wide scatter bands for any one alloy, and efficient utilization of alloy content will not be possible.

The results are discussed in somewhat greater detail in the following sections. Major emphasis has been placed on interpretation and application of the data.

Range in Properties:

The total range in properties produced by the treatments was very wide as the summary of Fig. 14 shows. Yield strengths at room temperature ranged from 30,000 to 134,000 psi. at 0.02 per cent offset. The stress for rupture in 100 hr. at 1200 F. varied from 40,000 to

66,000 psi. and in 1000 hr. from 35,000 to 56,000 psi. In terms of time for fracture, these results mean that in its weakest condition the alloy would fracture at 1200 F. under a stress of 40,000 psi. in 100 hr. In the strongest condition the alloy would carry the 40,000 psi. for an estimated 600,000 hr. Under a stress of 56,000 psi. the strongest condition would fracture in 1000 hr. at 1200 F., whereas the weakest condition would fail in a time period estimated as less than 0.1 hr. Ductility in the rupture test also varied over wide limits. The percentage elongation for fracture in 100 hr. ranged from one to 40.

These wide variations are significant for several reasons:

1. The most important is that processing and heat treatment must be controlled to obtain predictable properties or the highest strengths possible from the alloy. Rather wide variations in properties for several heats have been to a large extent a result of a lack of suitable control of the processing conditions.

2. The wide range in properties which have been observed for any one alloy in the hot-worked condition quite certainly is the result of the effects shown for heat treatment and hot-cold work. During hot working an alloy can be heat treated and hot-cold worked simultaneously. Therefore a range in properties is to be expected depending on the conditions of hot working.

3. The probability is that the hot-working conditions not only control properties in the hot-worked condition but also have a pronounced effect on the properties after most commercial solution, aging, and hot-cold working operations.

4. The absence of systematic correlations between chemical composition and properties for a wide range of alloys is believed to be largely the result of uncontrolled comparative processing and to the possibility that to attain optimum properties may require different treatments for each alloy.

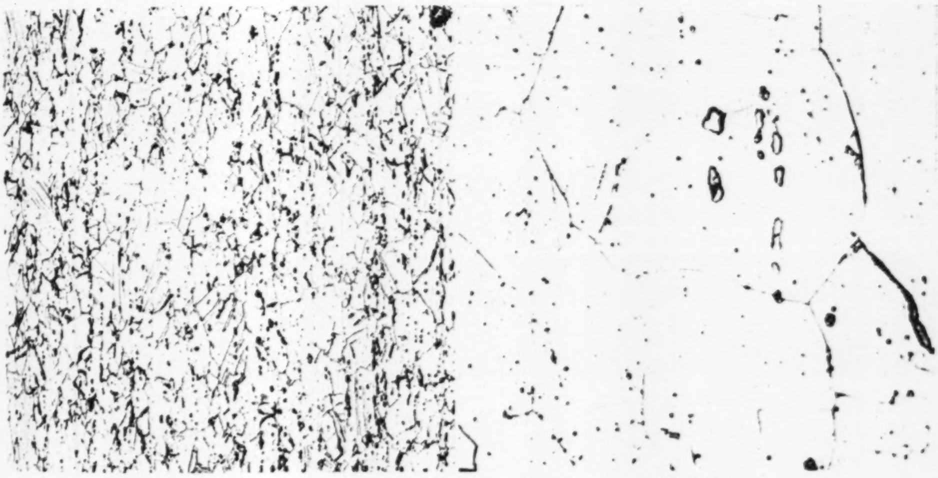
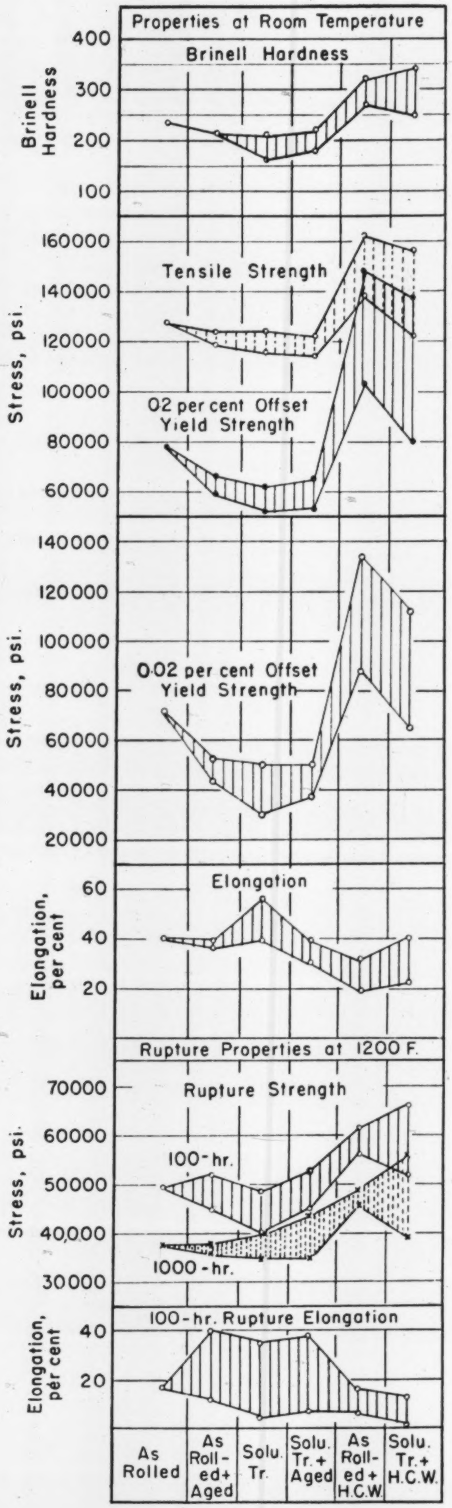

× 100 × 1000

FIG. 13.—Microstructure of Solution-Treated and Hot-Cold Worked Low-Carbon N-155 Bar Stock. Etched in electrolytic chromic acid.
Solution treated 2050 F., 2 hr., water quenched, and 25 per cent hot-cold work at 1200 F.



Aging Treatments–
1350 - 1750 F.

Solution Treatments–
1800 - 2300 F.

Hot-Cold Work – 5 – 25
per cent Reduction
at 1000 – 1800 F.

NOTE – The Ranges shown are those now Available and may not Cover all Possible Treatment.

Fig. 14.—Range in Properties of Low-Carbon N-155 Alloy for Various Types of Treatment.

Specific Effects of Treatment Conditions:

The metallurgist is continually faced with the necessity of specifying treatments for various applications. In general these must be based on many considerations. With the exception of manufacturing limitations, the most important are the strength and ductility at room temperature, the expected life, permissible deformation and required ductility at high temperatures. Restricting permissible deformation considerations to those defined by the rupture test and to a temperature of 1200 F., the data reported indicate:

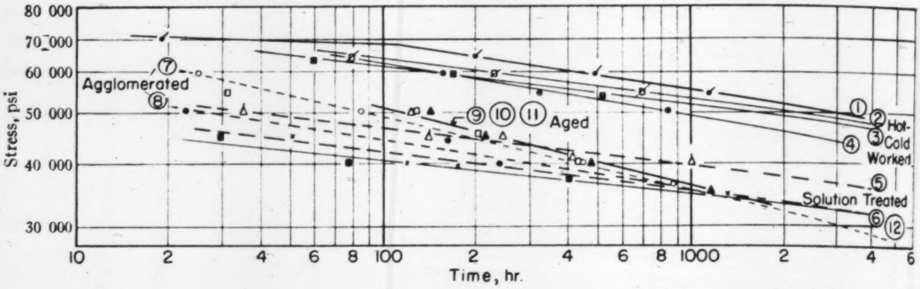
1. For short-time applications the hot-rolled and hot-cold worked stock produced the best combinations of strength and ductility. The difficulty with this finding is that it would probably be difficult to control hot-working conditions so that consistently uniform properties could be obtained, particularly ductility in the rupture test at 1200 F. Material hot-worked with a high reheat temperature, a high finishing temperature and a rapid cool would behave like solution-treated stock. Lowering the finishing temperature would introduce initial hot-cold work. Several reheats to too low a temperature for effective solution would result in material weakened by agglomeration of excess constituents.

2. Solution treatments alone result in low strength at room temperature and low short-time rupture strength at 1200 F. Solution-treatment temperatures above 2100 F. result in excessive brittleness under the low strain rates of the rupture test. Yield strengths for 0.02-per cent offset at room temperature of less than 40,000 psi. and rupture strengths of the order of 45,000 and 40,000 psi. for 100 and 1000 hr. are indicated by the data for the best solution treatments. These properties were obtained after a solution treatment at about 2100 F., a temperature at which the results are quite certain to be influenced by prior hot-working.

3. The major effect of aging was to increase ductility in the rupture test and to reduce rupture strengths at prolonged time periods. Low-carbon N-155 definitely appears to be an alloy which does not exhibit pronounced aging effects. The data definitely indicate that for predictable properties the best treatment is a high-temperature solution treatment followed by aging at 1350 to 1400 F., although there was surprisingly little effect from aging as high as 1750 F. The time of aging does not appear critical, 2 hr. producing about the same effect as the much longer times ordinarily used. Yield strengths at room temperature of the order of 40,000 to 50,000 psi. and rupture strengths at 1200 F. of about 50,000 and 40,000 psi. for 100 and 1000 hr. with adequate ductility appear to be typical for these treatments.

4. The high strengths considered characteristic of the alloy are dependent on hot-cold work. Maximum rupture strength at 1200 F. is obtained in effectively solution-treated stock by 10 to 15 per cent reduction at or below 1400 F. Such treatment should be expected to give yield strengths at room temperature of 90,000 to 110,000 psi. and rupture strengths as high as 63,000 psi. for 100 hr. and 55,000 for 1000 hr.

The ductility in the rupture test is considerably more complicated. Effectively solution-treated stock develops extreme brittleness after hot-cold work. The data in this report, indicating that the ductility after hot-cold work would be adequate with a solution temperature below 2200 F., could be misleading if original hot-working resulted in effective solution. It would seem therefore that it would be necessary in order to obtain both good strength and ductility to con-



No.	Symbol	Solution Treatment			Aging		Hot-Cold Work	
		Temp, F.	Time, hr.	Cooling	Temp, F.	Time, hr.	Temp. F.	Reduction per cent
1	✓	2050	2	W. Q.	— —	— —	1200	25
2	ø	2200	1	W. Q.	(1400	24)^a	1200	15
3	⊠	1950	2	W. Q.	— —	— —	1200	15
4	●	As Rolled			— —	— —	1200	15
5	Δ	2100	1	W. Q.	— —	— —	— —	— —
6	×	1800	2	W. Q.	— —	— —	— —	— —
7	○	(20 per cent Reduction at 1200 F. + 65 per cent Reduction from 1800 to 1400 F.)						
8	●	1800	2	Cool to	— —	— —	1400	20^b
9	△	As Rolled			1350	24	— —	— —
10	□	2050	2	W. Q.	1400	24	— —	— —
11	▲	2200	1	W. Q.	1600	24	— —	— —
12	■	2200	1	A. C.	— —	— —	— —	— —

a. Aged After Hot-Cold Work.

b. Process Repeated 6 Times.

FIG. 15.—Typical Curves of Stress Against Rupture Time for Low-Carbon N-155 Alloy.

TABLE III.— COMPARATIVE PROPERTIES OF LOW-CARBON N-155 DISKS AND BAR STOCK.

Material	Treatment	Room Temperature					1200 F. Rupture Properties			Data Source^a
		Brinell Hardness	Tensile Strength, psi.	Offset Yield Strengths, psi.		Elongation, per cent	100 hr., psi.	1000 hr., psi.	100-hr. Elongation, per cent	
				0.02 per cent	0.2 per cent					
Disk.....	As forged + 2 hr. at 1200 F.	235 ...	120 350	58 750 65 000	72 650 80 000	34.5 40	55 000	42 000	11	Ref. (5) A
Disk.....	As forged	210 ...	119 800	.... 50 000	65 000 70 000	44 40	46 000	38 500	9	Ref. (6) A
Bar.....	As rolled	233	128 500	72 500	78 500	40.5	49 500	37 500	17	B
Disk.....	As forged + 24 hr. at 1500 F.	232 ...	....	.... 60 000	.... 70 000	 35	47 000	33 500	36	Ref. (6) A
Bar......	As rolled + 24 hr. at 1500 F.	212	124 000	46 500	62 500	36	47 000	36 000	14	B
Disk....	2200 F. W.Q. + 24 hr. at 1350 F.	173 ...	106 000	.... 40 000	53 500 50 000	38 38	41 500	36 000	12	Ref. (6) A
Bar......	2200 F. W.Q. + 24 hr. at 1350 F.	205	120 125	54 000	64 000	38.5	53 000	39 500	15	B
Disk.....	2700 F. W.Q. + 24 hr. at 1500 F.	207 ...	114 000	.... 45 000	61 500 60 000	22.5 36	44 000	35 000	18	Ref. (6) A
Bar......	2200 F. W.Q. + 24 hr. at 1500 F.	202	121 750	50 000	63 500	36.5	49 000	35 000	25	B

[a] A = Estimated from Brinell hardness and data for bar stock in this paper.
B = Test data from this paper.

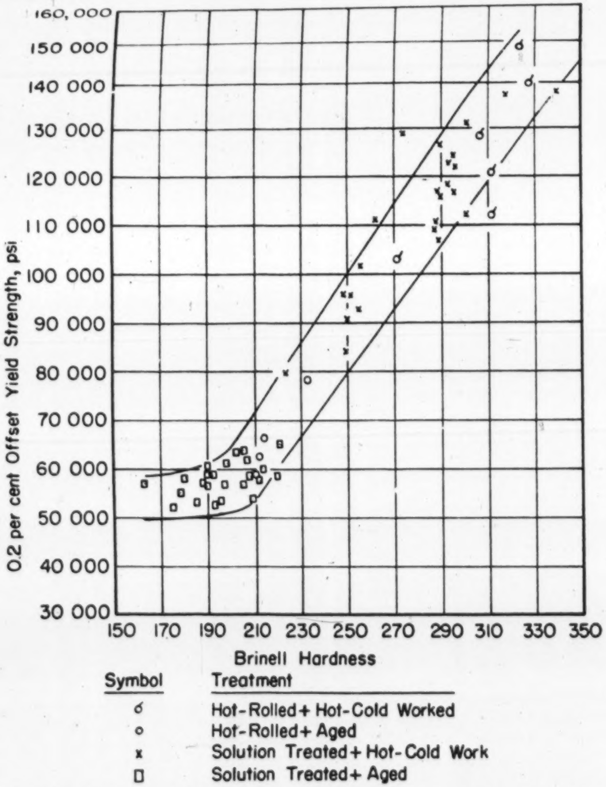


FIG. 16.—Relationship Between the Yield Strength of Low-Carbon N-155 Alloy at Room Temperature and Brinell Hardness.

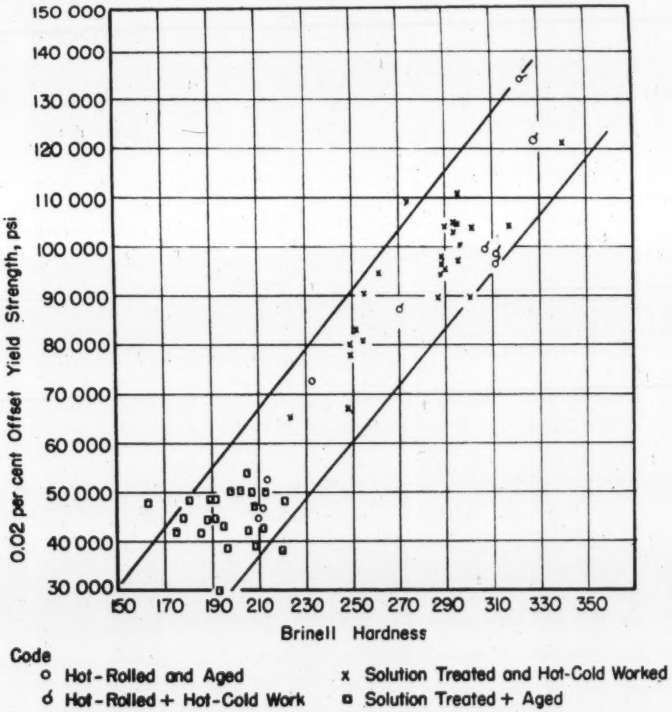


FIG. 17.—Relationship Between the Yield Strength of Low-Carbon N-155 Alloy at Room Temperature and Brinell Hardness.

trol hot-working conditions, age after hot-cold work, or sacrifice some strength and use a higher hot-cold working temperature.

Effect of Treatment on Properties for Prolonged Service:

The data indicate that effective solution treatment combined with hot-cold work produces the highest strengths for prolonged service at 1200 F. as well as for short-time service. Typical stress-rupture time curves illustrating the effects of the various typical treatments are shown by Fig. 15.

The curves for the solution-treated and hot-cold worked materials are parallel to, and at a higher stress level than, those for the material only solution-treated. Aging treatments after solution treatment apparently drastically reduce long-time strength.

In view of the commonly accepted belief that hot-cold work is detrimental to prolonged rupture strength, it appears that the stability of the hot-cold worked state varies widely from alloy to alloy and governs the usefulness of hot-cold work.

Correlation of Data:

One of the objectives of the investigation is to develop relationships which would permit checking the relative properties of any lot of low-carbon N-155 alloy by means of a few simple tests. The work has not yet progressed sufficiently to do so. Brinell hardness only predicts yield strengths to a range of 30,000 psi. as is shown by Figs. 16 and 17. There was no consistent relationship between hardness and rupture strength.

Published data for disks (**4, 5, 6**) of low-carbon N-155 alloy are compared with those for the bar stock of this paper in Table III. Average properties for the disks were in general lower than for the bar stock. Estimated values, based on the experience with the alloy obtained from the data in this paper and the difference in hardness between the disks and bar stock, were much closer together. This suggests that when actual conditions of prior treatment are the same, disks and bar stock will have the same properties; and the relative trends indicated by the data are not so much typical of the difference in disks and bar stock but of their conditions of treatment.

CONCLUSIONS

Systematic variation of treatments produced the following ranges in properties in one lot of low-carbon N-155 bar stock:

	0.02 per cent Offset Yield Strength at Room Temperature, psi.	Rupture Strength at 1200 F., psi.	
		100 hr.	1000 hr.
Solution treatments..	30 000 to 50 000	40 000 to 49 000	35 000 to 40 500
Aging treatments	38 000 to 52 700	45 000 to 53 000	35 000 to 44 000
Hot-cold work........	67 000 to 134 000	51 000 to 66 000	39 000 to 56 000

Solution treatments above 2100 F., particularly prior to hot-cold work, resulted in excessively low ductility and brittleness in the rupture test. The specific effects of treatment conditions varied depending on the time period for rupture. Hot-cold work gave the highest strength at 1200 F. for both long and short time periods. The major effect of aging was to increase ductility in the rupture test and reduce long-time rupture strength.

The strength ranges indicate the necessity for controlled processing for consistent and reproducible properties. It is suggested that hot-working conditions can have a pronounced effect on properties even after solution treatments up to 2200 F.

Wide scatter bands in the properties of alloys of the type considered are due, at least in part, to these factors. The absence of systematic correlations of properties and chemical composition are probably the result of uncontrolled comparative prior treatment and of the probability that treatment condition effects vary with composition.

The data indicate the necessity for more research work to determine the fundamental factors which control properties of the alloys of this type at high temperatures, extending the scope to include higher temperatures, creep characteristics, melting practice variables, and clarification of the effect of hot-working conditions.

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THE INFLUENCE OF FLUCTUATIONS IN STRESS AMPLITUDE ON THE FATIGUE OF METALS*

By T. J. Dolan,[1] F. E. Richart, Jr.,[2] and C. E. Work[1]

Synopsis

This paper describes the results obtained from an investigation dealing with the fatigue life of metals subjected to repeated stresses that fluctuated between two different predetermined amplitudes. Small high-speed rotating cantilever-beam fatigue testing machines applied to notched or unnotched specimens the general types of stress history studied. These were a type *G* loading cycle in which the amplitude of stress for each test was varied *gradually* and continuously between two limits designated as the minor and major stress amplitudes, and loading cycles *A* and *B* in which the stress amplitude was alternated *abruptly* at regular intervals between two predetermined values.

Studies were made of three steels and of 75S-T aluminum alloy, with the greatest emphasis on tests employing a loading cycle of the type *B*, in which each 1000 cycles of a major stress amplitude were followed by 9000 cycles of a lower (minor) stress amplitude. The range of values for the minor stress amplitude included several levels of overstress as well as of understress.

The change in fatigue life resulting from intermittent understressing depended not only on the magnitude of the understress but also on the magnitude of the major stress alternated with the understress. For major stresses only slightly above the original fatigue limit, a marked increase in total fatigue life resulted for unnotched specimens of all three steels; this was equivalent to an increase in fatigue limit. Cycles of understress (stresses below the fatigue limit) in load cycle *B* reduced the fatigue life of unnotched specimens of S.A.E. 1045 and S.A.E. 4340 steels, but did not produce a damaging effect in specimens of S.A.E. 2340 steel or of 75S-T aluminum alloy.

For conditions of overstressing in which only small differences existed between the magnitudes of the major and the minor stress amplitudes, the fatigue life was practically as long as though all stresses had been applied at the minor stress level; however, for higher values of major stress the fatigue life was shortened. In general, increased values of minor stress (if an overstress) resulted in a shorter fatigue life. Except in the cases cited above, failure occurred before the cumulative number of cycles at either the major or the minor stress amplitude reached the ordinary *S-N* curve.

The importance of obtaining further knowledge of the factors influencing progressive fracture of metals subjected to repeated applications of stress has long been recognized; various phenomena re-

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lated to the mechanism of fatigue failure have been studied for about one hundred years. Much has been learned from laboratory experiments, but no rational quantitative procedure has been developed for design of machine parts that are to be subjected to the types of repeated loading encountered under actual service conditions.

Conventional fatigue tests usually provide specific information regarding the life (number of cycles to failure) for a given type of specimen and for a test condition employing constant stress amplitudes. By altering the amplitude of stress from one test to the next, a series of values is obtained for the fatigue life, N, corresponding to any given level of stress, S.

In normal operation of high-speed mechanisms, the magnitude of the load on a member usually varies continuously with time; occasionally the moderate design stresses are exceeded, and a few cycles of very high stress (sometimes referred to as peak stress) are developed. Other intervals of idling or rest are often encountered, and a rather complicated stress history is built up during the normal life of the member. The beneficial and harmful effects on a member resulting from each phase of such a varied loading sequence cannot be associated directly with any *one* level of stress. The data contained in the conventional S-N diagram do not express the changing characteristics of the metal induced by overstressing[3], understressing[3], or rest periods, that are inherent in the normal stress history of a machine part. Additional studies and information are needed to determine the effect of these factors on the fatigue life of a member subjected to a stress history composed of fluctuating cycles of repeated stress (such as those shown in Figs. 2, 5 and 6).

Summary of Previous Work:

In order to determine the effect of repeated applications of *a given* stress on the capacity of the material to withstand subsequent repetitions of *other* levels of stress, several investigators have "prestressed" specimens at one stress level and then "retested" at a second level of stress. French (**1**)[4] investigated a "probable damage line" corresponding to the number of cycles at each given level of stress which could be applied without damaging a specimen; the specimen was presumed to have been damaged if it failed upon retesting at a stress equal to the original fatigue limit.

Kommers (**2, 3, 4**) made a comprehensive study of a somewhat different nature for evaluating the damaging effect of cycles of "overstress." After subjecting a group of specimens to a definite number of cycles of a given stress, the damage or strengthening produced was measured by retesting to determine the resulting change in fatigue limit. Bennett (**5**) also devoted considerable attention to the evaluation of the effects of prestressing by retesting and observing the relative number of cycles to produce failure at a second stress level.

The number of cycles run at the prestress divided by the fatigue life (as represented by the number of cycles to the conventional S-N curve at that prestress) was designated as the "cycle ratio." Bennett found that the number of cycles required to develop failure at the final test stress was nearly always less than the fatigue life of a virgin specimen at the test stress; the amount by which the number of cycles at the test stress was less than the normal fatigue life (expressed as per cent of the normal fatigue life) was termed "per cent damage" at the test stress.

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[3] Stresses greater than the fatigue limit are often referred to as "overstresses" and those less than the fatigue limit as "understresses."

[4] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 678.

For a series of tests (for example prestressing at 54,000 psi. and testing at 48,000 psi.) Bennett obtained the curve shown in Fig. 7 for the relation between cycle ratio at the prestress and per cent damage at the given test stress. This relation was valid for only a given sequence of these two stresses. Prestressing at 48,000 psi. and testing at the higher stress (54,000 psi.) gave a different curve for the relation between cycle ratio and damage. The results presented by both Bennett and Kommers show that the "stress history" is important in the determination of the fatigue properties of a material.

Müller-Stock, Gerold, and Schulz (6) also studied the effects of prestressing at various levels (usually above the fatigue limit) and evaluated the damage or strengthening by the change in fatigue life exhibited at one given stress level. A prestress which oscillated at regular intervals between two levels (below and above the fatigue limit) was applied in one series of tests.

None of these investigators attempted to apply fluctuating cycles of stress that were repeated until failure occurred. Stickley (7), however, did make a limited number of tests to fracture in which he subjected 25S-T aluminum alloy specimens to alternately high and low amplitudes of reversed flexural stresses. Stickley used three different ratios of: $\frac{\text{number of cycles at low stress}}{\text{number of cycles at high stress}}$, namely: 20 to 1, 50 to 1, and 200 to 1. He concluded that, in general, failure occurred when the number of cycles at either the low stress or the high stress approached the ordinary *S-N* curve for the material, regardless of the sequence in which the stresses were applied.

Langer (8), Thum and Bautz (9), Miner (10), Bollenrath (11), Richart and Newmark (12, 13), and others have presented certain theories of the behavior of metals subjected to fluctuating amplitudes of repeated stress, but as yet there is not sufficient experimental data available to verify any of the hypotheses presented. As a result there is no set procedure or specification to follow in designing a machine member for which the repeated stresses are expected to vary in amplitude during a normal service condition. The assumption is often made for ferrous metals (which exhibit a definite fatigue limit) that no damage to the material is developed by repetitions of stresses less than the fatigue limit (understresses) and hence that the fatigue life is controlled only by the peak stresses (overstresses) occurring during periods of overload. However, most non-ferrous metals do not exhibit a definite fatigue limit and presumably therefore might be damaged to some (unknown) extent by nearly all levels of applied stress. Furthermore, the tests of Bennett and Kommers indicated that the fatigue limit is itself a function of the previous stress history. Thus a stress thought to be an understress might actually be greater than the new fatigue limit of the metal after a given stress history and hence contribute to the cumulative fatigue damage of the metal.

Object and Scope of Investigation:

The purpose of this investigation was to make a laboratory study of the extent to which the fatigue life of several metals was affected by a stress history consisting of repeated stresses that fluctuated at regular intervals between two different predetermined amplitudes. Flexural fatigue tests were conducted on small specimens of three steels and of an aluminum alloy by employing the three different fluctuating loading cycles illustrated in Figs. 2, 5 and 6; conventional tests were also made in which the specimen was subjected to sinusoidally varying stress of constant amplitude (Fig. 3).

It was anticipated that the relative influence on fatigue life produced by applying different amplitudes of repeated stress might be determined for these simple types of stress history. This information would serve in a qualitative manner for evaluating the effect of a variable stress history such as might be encountered under actual service conditions. It was also hoped that further knowledge might be obtained regarding the significant criteria that govern the mechanism of fatigue damage to aid in explaining some of the puzzling phenomena observed by others in fatigue tests of specimens that had previously been repeatedly prestressed.

TABLE I.—CHEMICAL COMPOSITION AND HEAT TREATMENT OF METALS TESTED, PER CENT.

	S.A.E. 4340 Steel	S.A.E. 1045 Steel	S.A.E. 2340 Steel	75S-T Aluminum Alloy	
Carbon	0.39	0.44	0.40	Zinc	5.1 -6.5
Manganese	0.66	0.75	0.74	Copper	1.2 -2.0
Phosphorus	0.012	0.014	0.019	Magnesium	2.1 -2.9
Sulfur	0.018	0.021	0.020	Chromium	0.15–0.40
Silicon	....	0.21	0.28	Titanium	max. 0.2
Chromium	0.72	....	....	Manganese	max. 0.3
Nickel	1.72	....	3.48	Silicon	max. 0.5
Molydenum	0.35	....	....	Iron	max. 0.7
Iron	Remainder	Remainder	Remainder	Others	max ea. 0.05
					total 0.15
				Aluminum	Remainder
Heat treatment	Normalized at 1600 F. Oil Quenched from 1500 F. Drawn at 1150 F.	Normalized from 1550 F.	Oil-Quenched from 1450 F. Drawn at 1200 F.	Tested as received	

Experimental Investigation

Materials and Test Specimens

Preliminary exploratory tests were made on quenched-and-tempered samples from the same heat of S.A.E. 4340 steel used in previous studies by the Society's Research Committee on Fatigue of Metals (21). More extensive tests were later conducted on normalized S.A.E. 1045 steel, quenched-and-tempered S.A.E. 2340 steel, and 75S-T aluminum alloy, having the chemical analyses and heat treatments listed in Table I. All specimens were cut from round bars $\frac{3}{4}$ in. or $\frac{7}{8}$ in. in diameter.

After heat treatment, the static tensile properties were determined by tests made on specimens of the types shown in Figs. 8a and 8b; sample tensile stress-strain diagrams for three materials in the condition tested are shown in Fig. 10. Standard Charpy bending impact tests were made on three to five specimens of the S.A.E. 2340 steel and the

TABLE II.—MECHANICAL PROPERTIES OF METALS TESTED.

Material	S.A.E. 4340 Steel	S.A.E. 1045 Steel	S.A.E. 2340 Steel	75S-T Aluminum Alloy
Tensile strength, psi	150 400	97 300	117 200	83 680
Yield point, psi	142 200	59 800	99 500	73 060[a]
Elongation in 2 in., per cent	18.2	27.8	23.5[b]	16.0
Reduction in area, per cent	61.0	47.5	66.5	31.6
Charpy impact, ft-lb			96.0	5.0
Brinell hardness, (3000-kg. load)	322	190	245	178.5
Rockwell hardness		B—89.6	C—21.4	B—91.2

[a] Yield strength, 0.2 per cent offset.

[b] For specimens of the type in Fig. 8 (*b*), 2-in. gage length = 6 diameters.

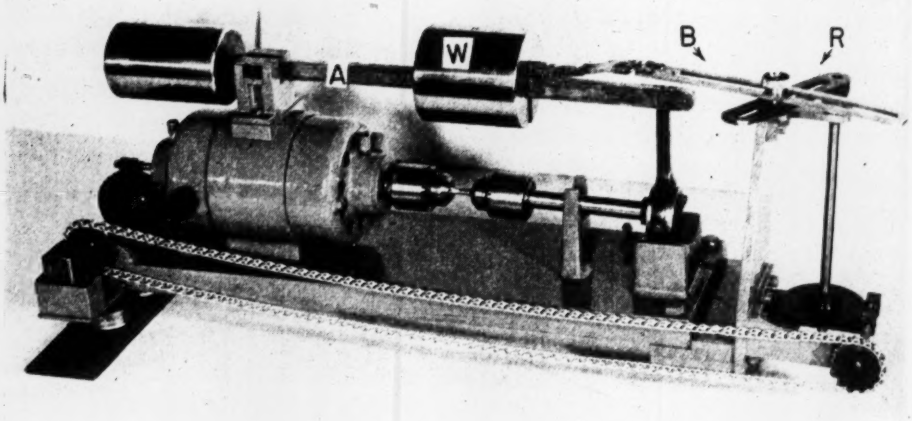


FIG. 1.—High Speed Cantilever Fatigue Machine Constructed to Apply Load Cycle *G*.

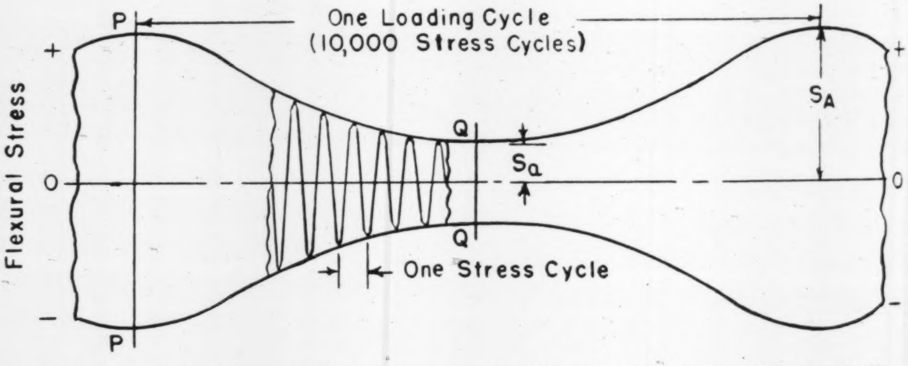

P
One Loading Cycle
(10,000 Stress Cycles)
+
Flexural Stress
0
−
Q
S_a
S_A
Q
One Stress Cycle
P
+
0
−

FIG. 2.—Amplitude Pattern of Stresses Developed by Machine Shown in Fig. 1 (Load Cycle *G*).

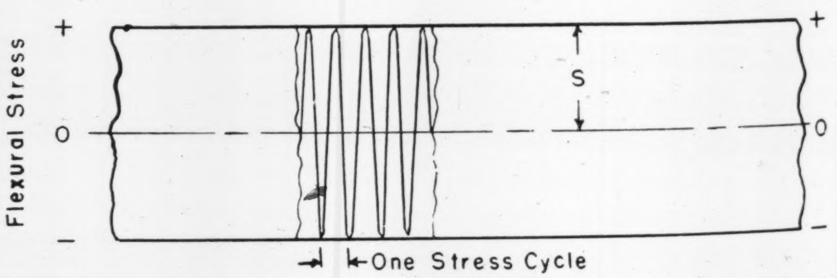

+
Flexural Stress
0
−
S
One Stress Cycle
+
0
−

FIG. 3.—Amplitude Pattern of Stresses Developed Under Constant Load for Determination of *S-N* Curves (Load Cycle *C*).

aluminum alloy (details of the impact specimens used are shown in Fig. 8c).

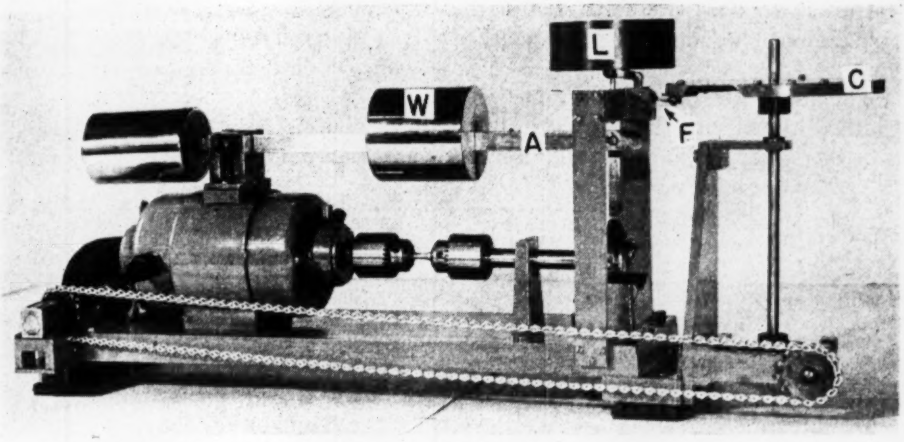


FIG. 4.—High Speed Cantilever Fatigue Machine Modified to Apply Load Cycle *B*.

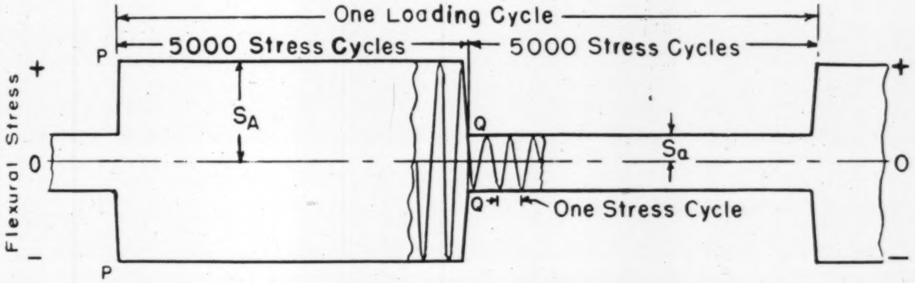

One Loading Cycle
5000 Stress Cycles
5000 Stress Cycles
P
P
Q
Q
S_A
S_a
One Stress Cycle
Flexural Stress
+
0
–
+
0
–

FIG. 5.—Amplitude Pattern of Stresses Developed in Load Cycle *A*.

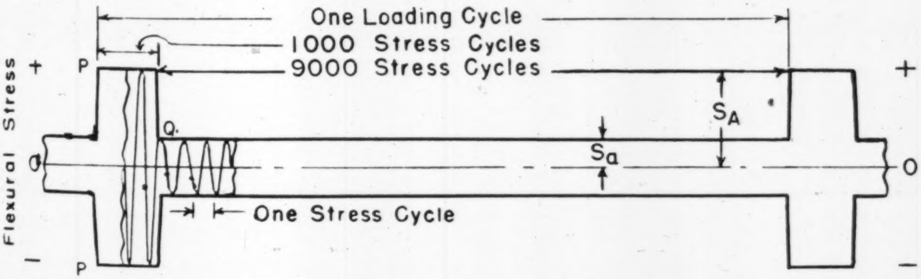

One Loading Cycle
1000 Stress Cycles
9000 Stress Cycles
P
P
Q
S_A
S_a
One Stress Cycle
Flexural Stress
+
0
–
+
0
–

FIG. 6.—Amplitude Pattern of Stresses Developed by Machine Shown in Fig. 4 (Load Cycle *B*).

The average results obtained from the tension, impact, and hardness tests are listed in Table II.

The fatigue studies included tests of both notched and unnotched specimens of the types shown in Fig. 9. The critical diameters were selected for each metal so that the strength characteristics of the specimen could be accommodated by the loading range of the fatigue machine.

The design of the notched specimen was chosen as one that could be readily reproduced yet develop a fairly severe "stress raiser" for comparison with the companion "unnotched" or polished specimens.

The unnotched fatigue specimens were finished by polishing longitudinally with No. 00 emery paper and oil; notched specimens were *not* polished but were cut using sharp tools carefully honed to shape and examined in an optical comparator to assure uniformity of angle, root radius, and notch depth.

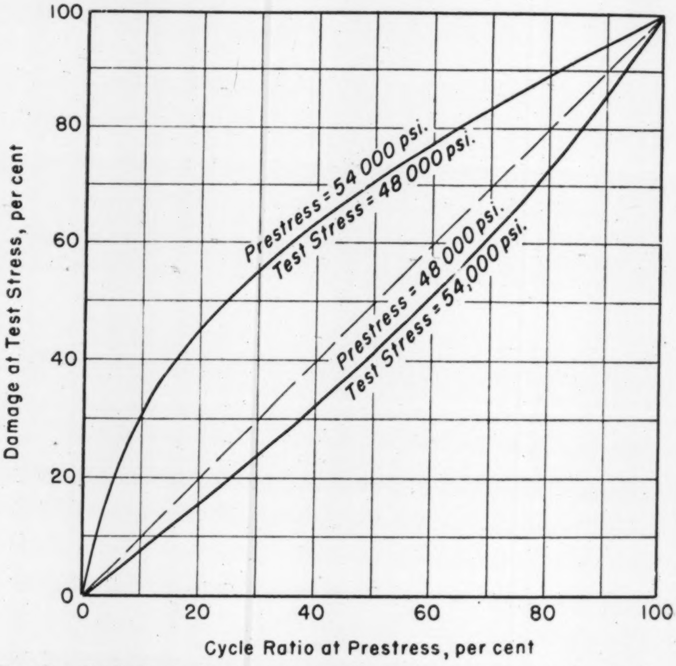


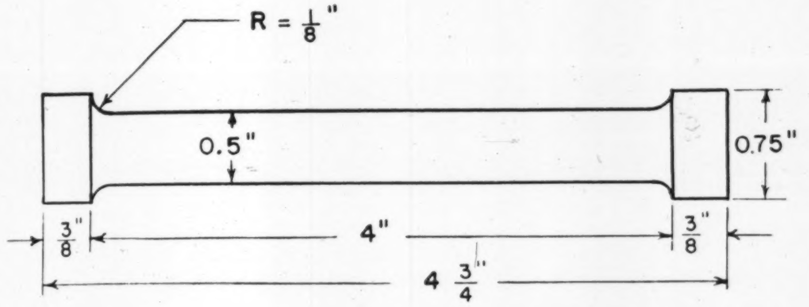
FIG. 7.—Cycle Ratio Damage *versus* Curves (From Bennett (5), Fig. 7).

Fatigue Machines and Testing Procedure:

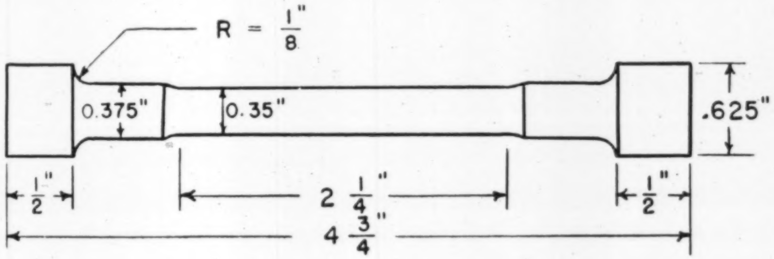
The four machines used were small high-speed rotating cantilever-beam fatigue testing machines constructed at the University of Illinois and were of the types shown in Figs. 1 and 4. These machines were run continuously at a nominal speed of 10,000 rpm. during the life of a specimen.

For determination of the ordinary S-N curves (shown in Figs. 11 to 15), the stress history produced in the outer fibers at the critical section of the specimen was of the type C shown in Fig. 3 in which the stress amplitude, S, remained constant throughout the life of the specimen. The stresses were applied by use of a machine of the type shown in Fig. 1, but with the crank arm, R, and the connecting rod assembly, B, *removed*. The specimen was held at both ends in small Jacobs chucks, and the stress was determined by the position of the weight, W, on the loading lever, A, which was calibrated in terms of the bending moment at the critical section of the specimen.

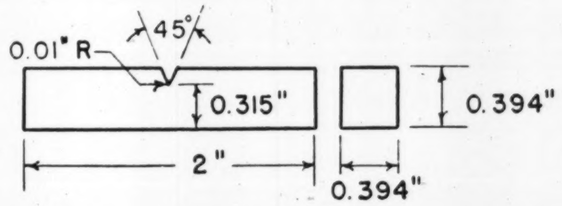
The nominal stress in the extreme fibers at the critical section of both notched and unnotched specimens was computed by use of the flexure formula, $S = \frac{Mc}{I}$; no allowance was made for the stress concentration resulting from the abrupt change of section in the notched-type specimen.



(a) Specimen for Static Tension Test of SAE 1045 Steel, SAE 4340 Steel, and 75S-T Aluminum Alloy.



(b) Specimen for Static Tension Test of SAE 2340 Steel.

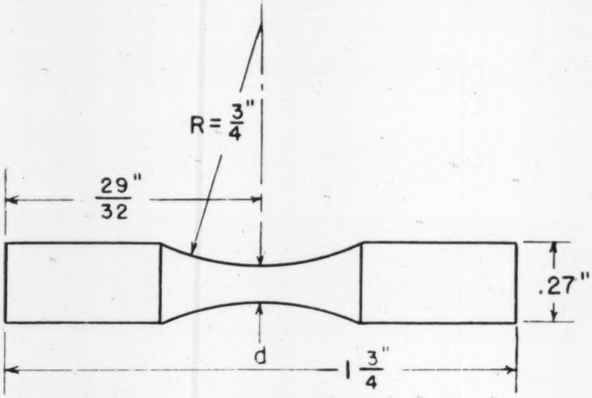


(c) Specimen for Charpy Impact Test.

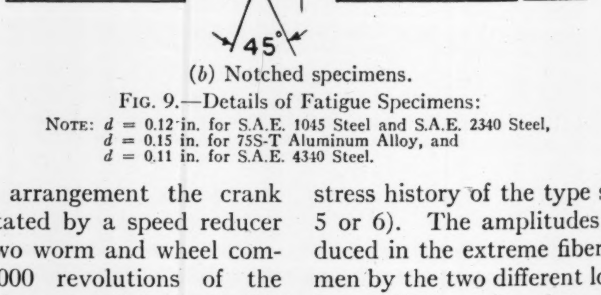
FIG. 8.—Details of Static Tension and Bending Impact Specimens.

Tests in which a rotating cantilever-beam specimen was repeatedly subjected to stress whose amplitude varied gradually between two predetermined limits (Fig. 2) will be referred to as employing load cycle *G*. In this load cycle, the stress amplitude fluctuated from a maximum to a minimum value and back to the maximum value during each 10,000 revolutions of the specimen. The upper limit of stress amplitude in a given test will be termed "major stress amplitude" and will be represented by the symbol S_A, whereas the lower limit of the stress amplitude will be called the "minor stress amplitude" and will be represented by the abbreviation S_a (Fig. 2).

Load cycle *G* was produced by the machine with the crank arm *R* and connecting rod *B* installed as shown in Fig. 1. With this arrangement the crank arm *R* was rotated by a speed reducer consisting of two worm and wheel combinations; 10,000 revolutions of the motor produced one complete revolution of the crank arm. The rotary motion of the crank arm operated connecting rod *B* to develop a reciprocating motion of the weight, *W*. Adjustments for range of load and minimum load were made at the junction of the crank arm and the connecting rod by means of a pivot which clamped to each piece separately.



(*a*) Unnotched specimens.



(*b*) Notched specimens.

FIG. 9.—Details of Fatigue Specimens:

NOTE: d = 0.12 in. for S.A.E. 1045 Steel and S.A.E. 2340 Steel,
d = 0.15 in. for 75S-T Aluminum Alloy, and
d = 0.11 in. for S.A.E. 4340 Steel.

In other tests the magnitude of the load applied to a rotating-beam specimen was changed abruptly between two predetermined values at regular intervals (the specimen was subjected to a stress history of the type shown in Figs. 5 or 6). The amplitudes of stress produced in the extreme fibers of the specimen by the two different loads in a given test will be referred to as the major stress amplitude S_A and the minor stress amplitude S_a. To produce this type of stress history the original fatigue machines were equipped as illustrated in Fig. 4. In conducting a test, the desired minimum load was applied by the weight, W, and the maximum load was obtained by the addition of a predetermined weight of shot in a small container, L. The cam C rotated through one complete revolution during each 10,000 revolutions of the specimen; the cam follower, F, alternately applied or lifted the supplemental load from the loading arm.

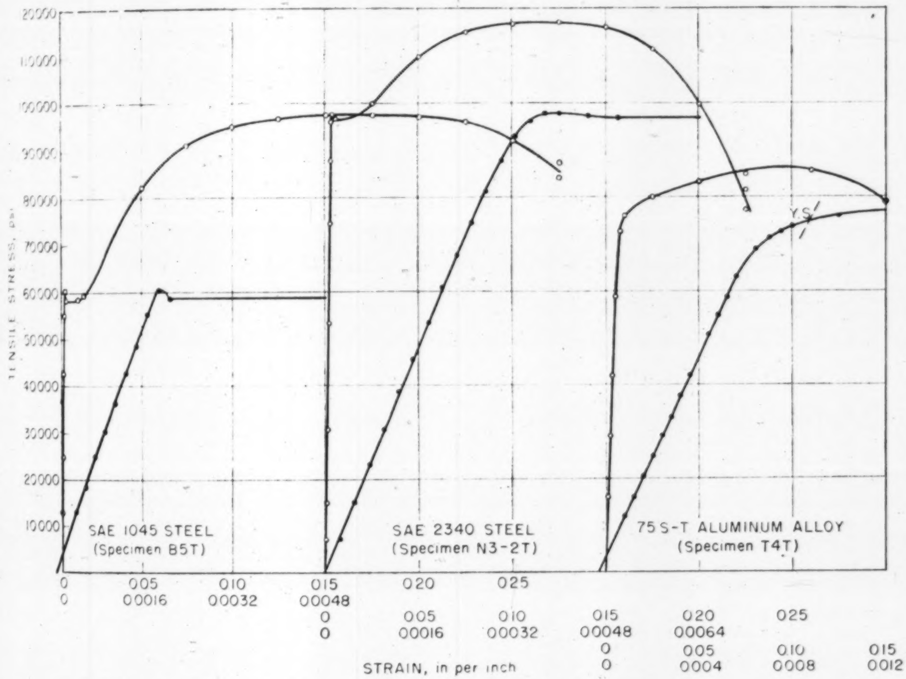


FIG. 10.—Static Tensile Stress-Strain Curves for Metals Used in Tests.
(Use lower strain scale for solid symbols which show lower portions of stress-strain curves.)

It will be noted that the particular cam shown in Fig. 4 was designed to produce a two-load cycle of the type B (Fig. 6) in which the greater load was applied for 1000 out of each 10,000 cycles; this loading cycle was repeated at the same two levels of stress amplitude until failure of the specimen occurred.

The second two-load cycle of the type A (Fig. 5), in which the greater load was in effect for 5000 out of each 10,000 cycles, was produced by substituting a different cam, C, that was designed to apply the supplementary load to the specimen during one-half of each evolution of the cam.

In order to be consistent, the majority of tests were initiated at the major stress amplitude (at P in Figs. 2, 5, and 6). However, some specimens of both notched and unnotched S.A.E. 4340 steel were started at the (lower) minor stress amplitude (at Q in Figs. 2 and 5) to determine whether interchanging the initial sequence of applying the major and minor stress amplitudes had an effect on fatigue life.

Experimental Results:

The data from conventional fatigue tests employing a constant stress amplitude are shown for the various metals in Figs. 11 to 15; S-N curves have been

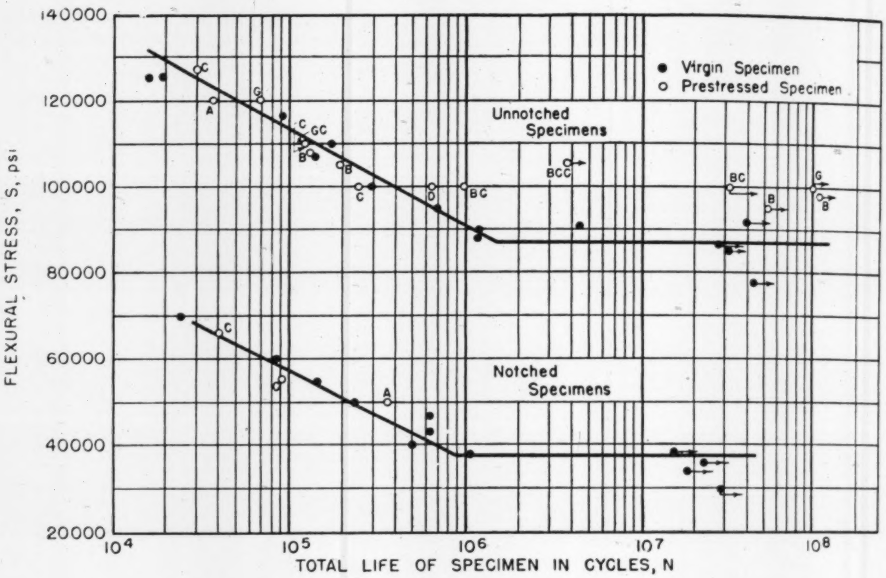


FIG. 11.—*S-N* Curves for S.A.E. 4340 Steel.

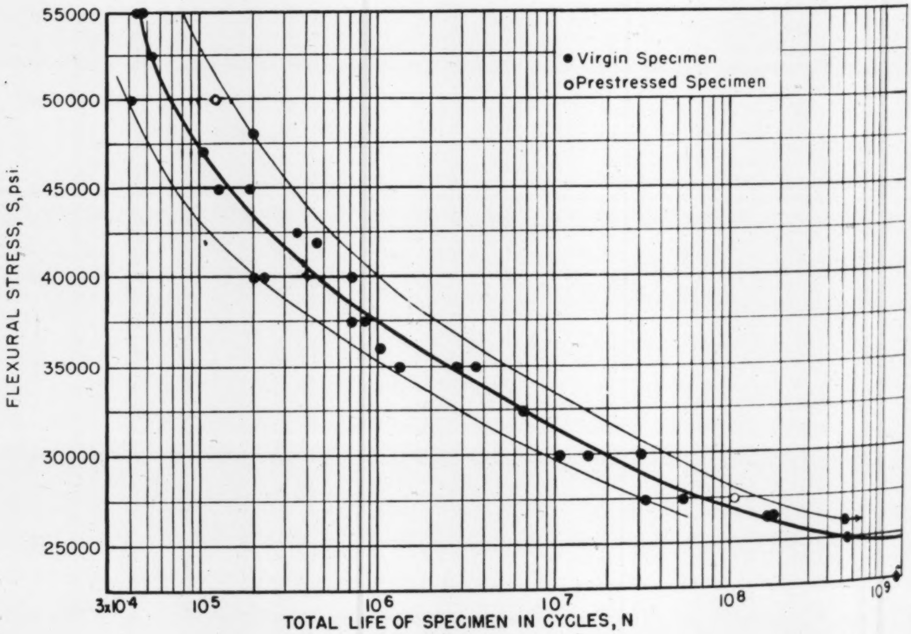


FIG. 12.—*S-N* Curve for Unnotched Specimens of 75S-T Aluminum Alloy.

drawn in to represent an approximate average of the test points (solid circles), and in Figs. 12 and 14 the approximate "scatter band" has been bounded by curves. In subsequent figures these same *S-N* curves and scatter bands have been reproduced without showing the original test points from which they were obtained.

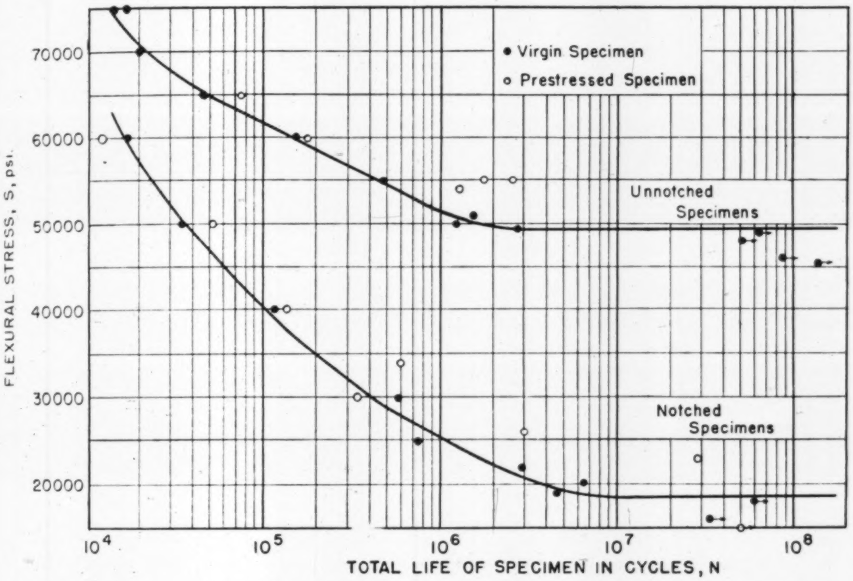


FIG. 13.—*S-N* Curves for S.A.E. 1045 Steel.

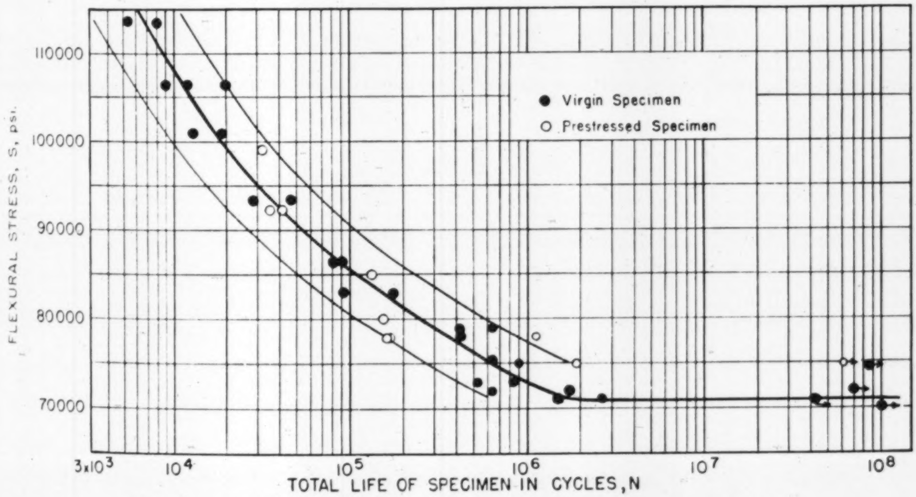


FIG. 14.—*S-N* Curve for Unnotched Specimens of S.A.E. 2340 Steel.

It may be observed (Fig. 12) that failure occurred in some specimens of 75S-T aluminum alloy after many millions of repetitions of stress; that is, no definite fatigue limit was exhibited.

Comparisons were therefore made on the basis of a fatigue strength, S_n, for the 75S-T alloy corresponding to the amplitude of stress that would produce fracture at approximately 500,000,000 repetitions of stress. To avoid delay in starting a program of experiments on the 75S-T alloy with the type *B* load

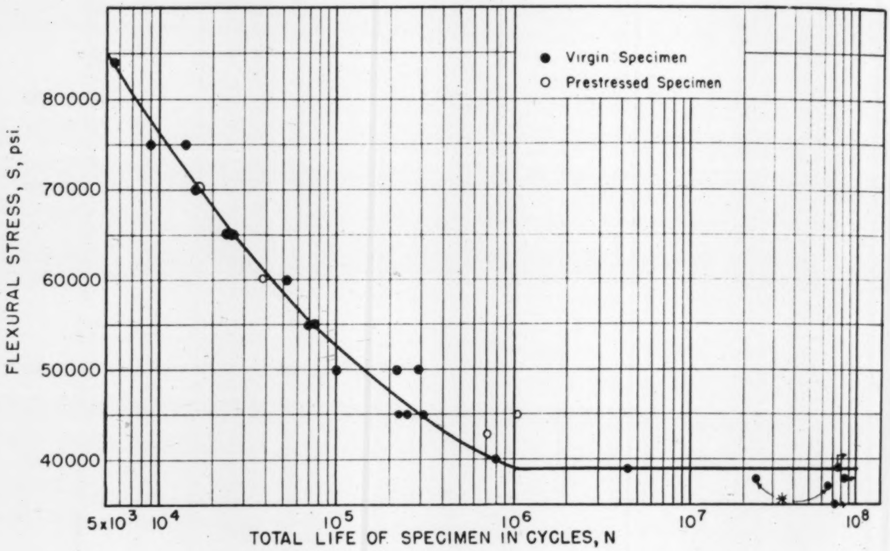


FIG. 15.—*S-N* Curve for Notched Specimens of S.A.E. 2340 Steel.
* Failures can be attributed to vibration of machine arising late in test from external sources.

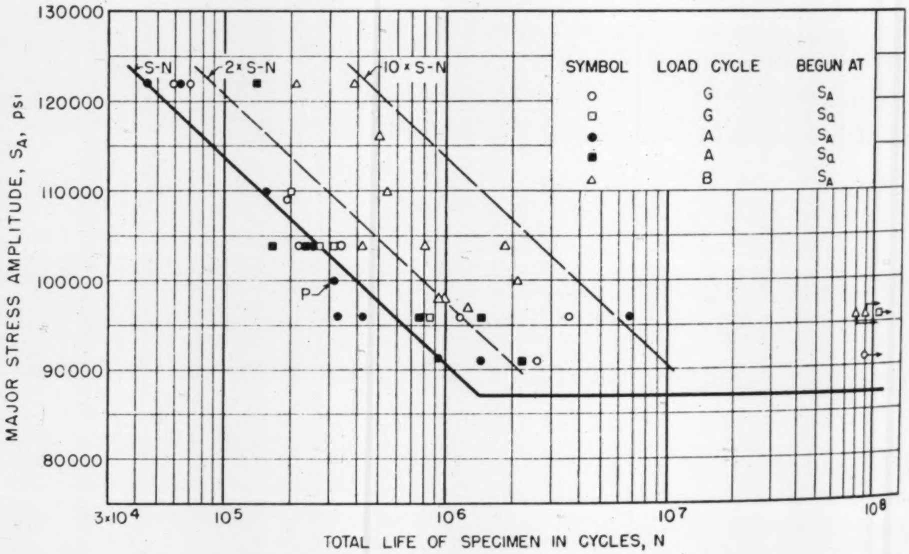


FIG. 16.—Test Results for Unnotched Specimens of S.A.E. 4340 Steel Subjected to Fluctuating Cycles of Loading in Which the Minor Stress Amplitude was 78,000 psi.

cycle, an approximate fatigue strength S_n = 24,000 psi. was estimated after a few initial tests. This estimated value for the fatigue strength was used in selecting levels of stress amplitude (S_A and S_a) rather than the value of 25,000 psi. which was determined later from more complete test data.

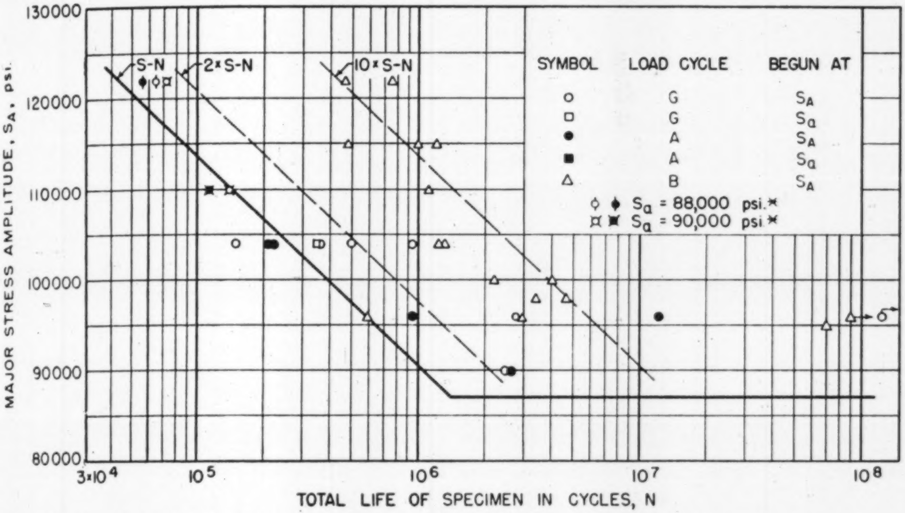


FIG. 17.—Test Results for Unnotched Specimens of S.A.E. 4340 Steel Subjected to Fluctuating Cycles of Loading.

*The minor stress amplitude was 60,000 psi. in all tests plotted above except those indicated otherwise in the legend.

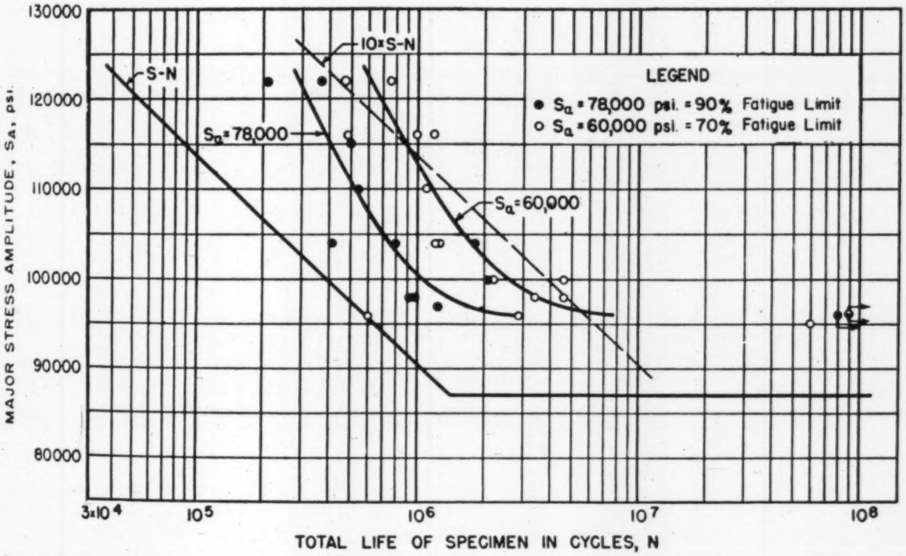


FIG. 18.—Test Results for Unnotched Specimens of S.A.E. 4340 Steel Subjected to Load Cycle *B*.

Each of the *steels* tested exhibited a definite fatigue limit, that is, a stress below which no fatigue failure occurred. The values of the original fatigue limit

S_e for the steels and for the fatigue strength S_n of the aluminum alloy are shown in Table III.

Some of the specimens tested at stresses near the fatigue strength did not fail after many millions of repetitions of stress; the test was therefore stopped and the specimen later retested. The total number of cycles in the original test was plotted with a small arrow to the right to indicate that failure had not occurred. The original test thus constituted a prestressing involving millions of cycles of a particular stress history after which the specimen was retested at a higher stress of constant amplitude.

The life to failure at the final test stress is plotted by means of open circles in Figs 11 to 15. The previous stress history for some of these specimens involved only one constant stress amplitude (load cycle *C*) whereas for other specimens the previous stress history was of one of the fluctuating types (load cycles *A*, *B*, or *G*). These retest results were plotted on the corresponding *S-N* diagrams in order to facilitate comparison with the length of life of virgin specimens tested at the same stress amplitude. The complete stress history is presented in Table IV for all specimens that were retested; a detailed discussion of these data will be presented in a later section.

TABLE III.—CONVENTIONAL FATIGUE STRENGTHS.

Material	Fatigue Strength, psi.	
	Unnotched Specimens	Notched Specimens
S.A.E. 4340 steel	87 000	39 000
75S-T aluminum alloy	25 000[a]	. . .
S.A.E. 1045 steel	49 500	18 500
S.A.E. 2340 steel	71 000	39 000

[a] Based on 500,000,000 cycles of stress.

The fatigue data for specimens subjected to fluctuating cycles of loading are plotted in Figs. 16 to 19 and Figs. 21 to 26. The ordinate to each point in these figures represents the magnitude of the major stress amplitude (S_A in Figs. 2, 5, and 6) and the abscissa represents the *total life of the specimen* (cycles of stress) accumulated at both the major and minor stress amplitudes. In some instances (Figs. 25 and 26) for which the fatigue life of two specimens subjected to the same loading cycle was practically identical, the point was marked "2" and the symbol plotted only once. The type of symbol used in plotting each point indicates the magnitude of the minor stress amplitude as shown in the legend accompanying each figure. In several of these diagrams which present data from all three types of load cycle, the symbols also indicate the type of stress history developed. The type *A* and type *G* load cycles were not utilized in the later tests (of S.A.E. 2340 steel or of 75S-T aluminum); the data plotted in Figs. 23 to 26 include results from load cycle *B* only.

The ordinary *S-N* curves have been reproduced in Figs. 16 to 19 and Figs. 21 to 26 to facilitate comparison with the fatigue properties obtained for similar specimens subjected to fluctuating cycles of loading. To the right of the *S-N* curve (solid) in these figures is plotted a broken curve labeled "10 × *S-N*," and another curve in several of these figures is labeled "2 × *S-N*." These curves have the same shape as the *S-N* curve but are offset along the abscissa by factors of ten and two respectively.

It will be recalled that for load cycle *B* (Fig. 6) only one tenth of the total number of stress cycles were at the higher stress amplitude, S_A. If it were assumed that repetitions of the minor stress amplitude, S_a had no damaging or strengthening effect on the specimen, failure would be expected to occur at a *total* life represented by the curve 10 × *S-N* (corresponding to the condition for which the cumulative number of stress cycles *at only the major stress* reached the ordinary

TABLE IV.—FATIGUE STRESS HISTORY FOR SPECIAL RETESTS.

Specimen Number	Prestress History					Retest Data	
	Loading Cycle[a]	S_A, psi.	S_a, psi.	Total Life, cycles	Rest, days	Stress, S, psi.	Life at S Cycles
NOTCHED SPECIMENS OF S.A.E. 4340 STEEL							
V 8	*C*	36 000		22 848 000	10	66 000	41 000
V 5	*C*	36 500		18 218 000	20	55 000	92 000
W 12	A	43 000	35 000	49 854 000	21	50 000	353 000
UNNOTCHED SPECIMENS OF S.A.E. 4340 STEEL							
1	*C*	77 600		44 502 000	24	127 000	30 000
W 22	*C*	92 000		39 361 000	37	110 000	111 000
7	*C*	86 500		27 299 000	158	100 000	240 000
W 65	*B*	94 000	60 000	69 286 000	3	108 000	132 000
W 43	*B*	96 000	78 000	90 000 000	1	105 000	188 000
V 51	*A*	89 000	78 000	78 019 000	1 hr. 4 min.	120 000	38 000
W 34	*G*	96 000	78 000	104 311 000	13	120 000	68 000
W 46	*G*	91 000	78 000	90 022 000	2 hr. 23 min.	100 000	631 000
W 48	*B*	96 000	78 000	80 000 000	2 min.	95 000	52 974 000[b]
			Second Retest		0	100 000	985 000[c]
W 26	*G*	96 000	60 000	137 925 000	20	100 000	101 900 000[b]
			Second Retest		2 hr. 50 min.	110 000	110 000[c]
W 67	*B*	96 000	60 000	88 620 000	19 min.	98 000	111 394 000[b]
			Second Retest		0	100 000	32 314 000[b,c]
			Third Retest		0	105 000	3 869 000[d]
NOTCHED SPECIMENS OF S.A.E. 1045 STEEL							
B 8	*C*	18 000		60 000 000	14	50 000	52 000
B 7	*C*	16 000		33 631 000	19	30 000	339 000
B 23	*B*	25 900	14 800	90 000 000	1 hr. 13 min.	23 000	29 368 000
B 13	*A*	25 900	14 800	82 545 000	2	40 000	137 000
B 12	*A*	22 200	14 800	65 179 000	8	26 000	2 972 000
B 14	*G*	22 000	14 500	133 359 000	2 hr. 43 min.	60 000	12 000
B 15	*G*	33 300[e]	14 800	1 804 000	7	15 000	50 000 000[b]
			Second Retest		3 hr. 22 min.	34 000	605 000[c]
UNNOTCHED SPECIMENS OF S.A E. 1045 STEEL							
B 36	*C*	45 400		138 469 000	1	65 000	74 000
B 33	*C*	48 000		51 580 000	14	60 000	178 000
B 34	*C*	49 000		63 624 000	10	55 000	2 536 000
B 32	*C*	46 000		85 501 000	14	54 000	1 282 000[f]
B 84	*B*	51 500	45 000	77 413 000	0	55 000	1 790 000
NOTCHED SPECIMENS OF S.A.E. 2340 STEEL							
N 48	*B*	40 000	31 000	100 164 000	63	70 000	16 000
N 55	*C*	35 000		71 621 000	41 min.	60 000	38 000
N 15	*C*	39 000		75 600 000	1 hr. 7 min.	45 000	1 031 000
N 53	*C*	38 000		85 344 000	5 min.	43 000	705 000
UNNOTCHED SPECIMENS OF S.A.E. 2340 STEEL							
N 98	*C*	72 000		69 672 000	27	99 400	32 000
N 65	*C*	74 700		86 245 000	31	92 300	36 000
N 121	*C*	71 000		42 325 000	27	85 200	132 000
N 125	*C*	70 000		99 766 000	16	78 000	162 000
N 165	*B*	78 000	71 000	84 812 000	8	92 300	42 000
N 150	*B*	79 000	71 000	70 011 000	7 hr. 33 min.	80 000	154 000
N 173	*B*	76 000	56 800	43 151 000	5 hr. 23 min.	75 000	61 728 000[b]
			Second Retest		1	78 000	168 000[c]
N 99	*B*	78 000	71 000	30 480 000	19	78 000	1 121 000
N 126	*B*	78 000	71 000	45 752 000	36	75 000	1 911 000
UNNOTCHED SPECIMENS OF 75S-T ALUMINUM ALLOY							
T 37	*C*	22 500		1 291 995 000	260	50 000	126 000
T 165	*C*	26 000		525 928 000	254	27 500	107 529 000

[a] Shown in Figs. 2, 3, 5, and 6.
[b] Did not fail at test stress. Retested at still higher level.
[c] Retested after failure did not occur in previous tests.
[d] Machine broke down damaging specimen which had not failed at this life.
[e] Loading changed at unknown time to load of at least 14,000 psi.
[f] Received slight plastic bend while being removed from machine after original test.

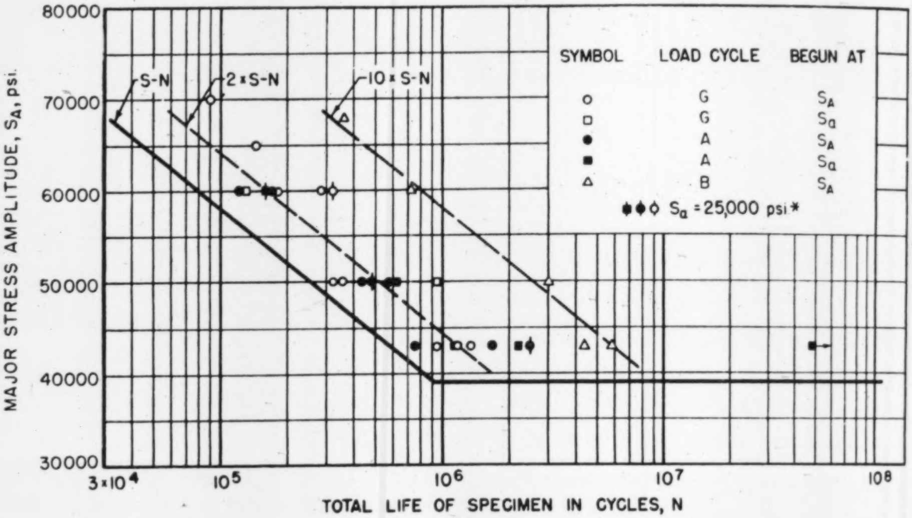


FIG. 19.—Test Results for Notched Specimens of S.A.E. 4340 Steel Subjected to Fluctuating Cycles of Loading.

* The minor stress amplitude was 35,000 psi. in all tests plotted above except those indicated otherwise in the legend

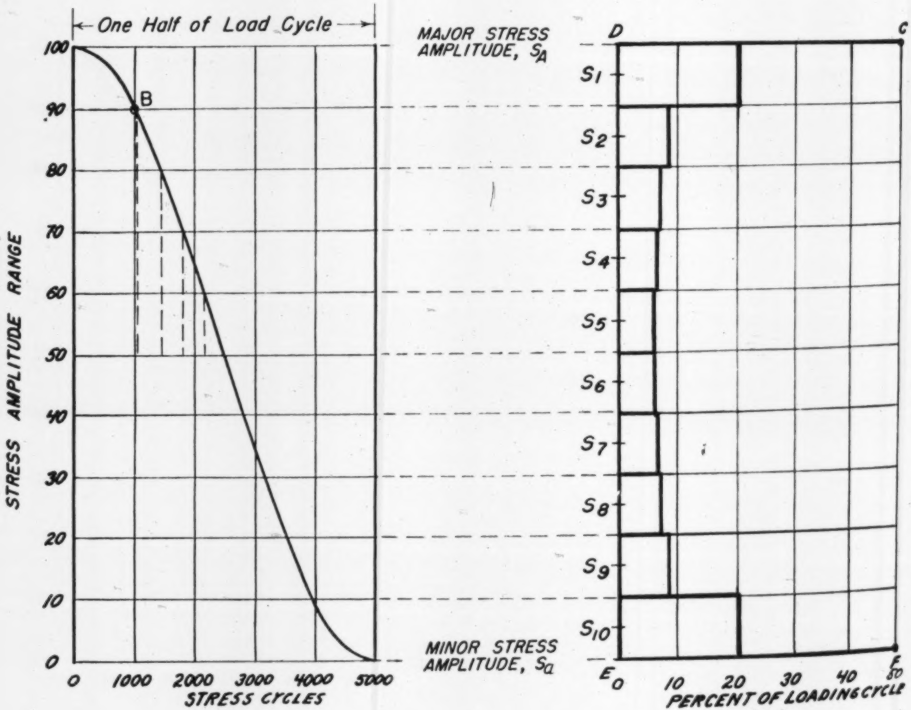


FIG. 20.—Frequency Distribution for Stresses Produced by Load Cycle G.

S-N curve). Similarly, if repetitions of the minor stress amplitude had no damaging or beneficial effect, the total fatigue life obtained in tests using load cycle *A* should fall along the curve 2 × *S-N*.

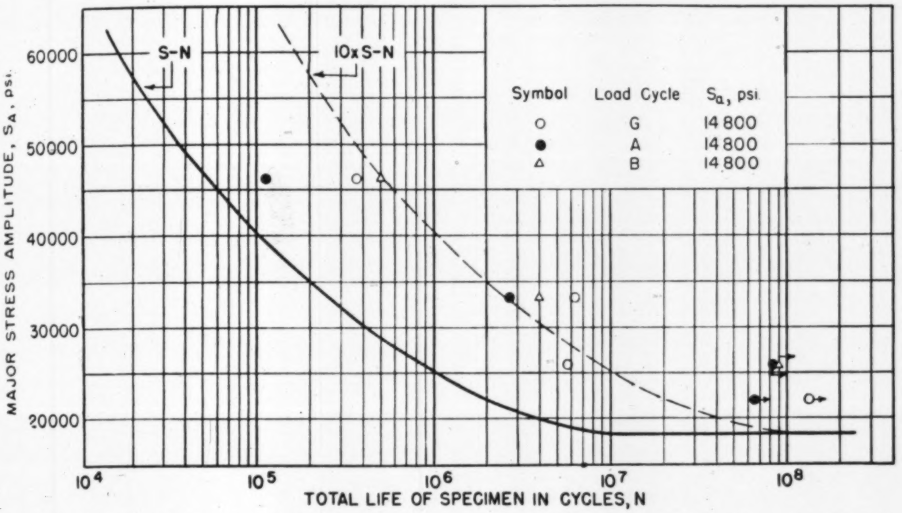


FIG. 21.—Test Results for Notched Specimens of S.A.E. 1045 Steel Subjected to Fluctuating Cycles of Loading.

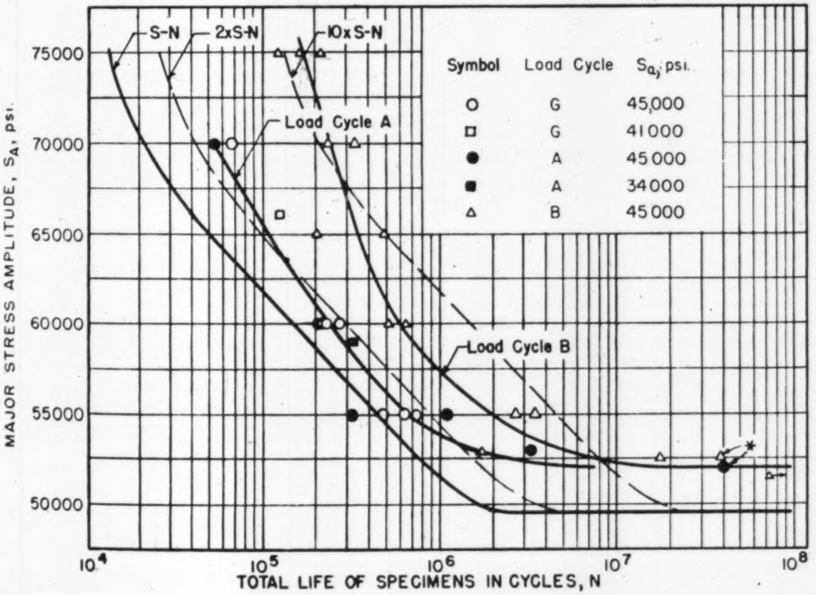


FIG. 22.—Test Results for Unnotched Specimens of S.A.E. 1045 Steel Subjected to Fluctuating Cycles of Loading.

*Failures can be attributed to vibration of machine arising late in test from external sources.

As an illustrative example of the method of plotting these data, the point *P* in Fig. 16 represents a specimen whose *total* fatigue life was 314,000 cycles. As indicated in the legend, this solid circular symbol indicates that the stress history (type *A*) consisted of 5000 reversed cycles at $S_A = 100{,}000$ psi., followed by 5000 reversed cycles at $S_a = 78{,}000$ psi.; this loading cycle was repeated until fracture occurred. If this test had been conducted at constant stress amplitude ($S_A = S_a = 100{,}000$ psi.) the conventional *S-N* curve indicates that the total fatigue life should have been approximately 400,000 cycles. However, half

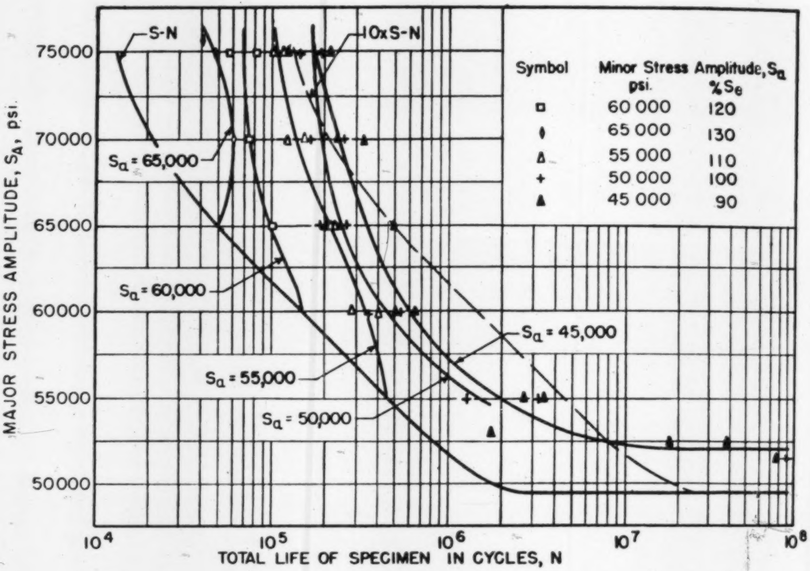


FIG. 23.—Test Results for Unnotched Specimens of S.A.E. 1045 Steel Subjected to Load Cycle *B*.

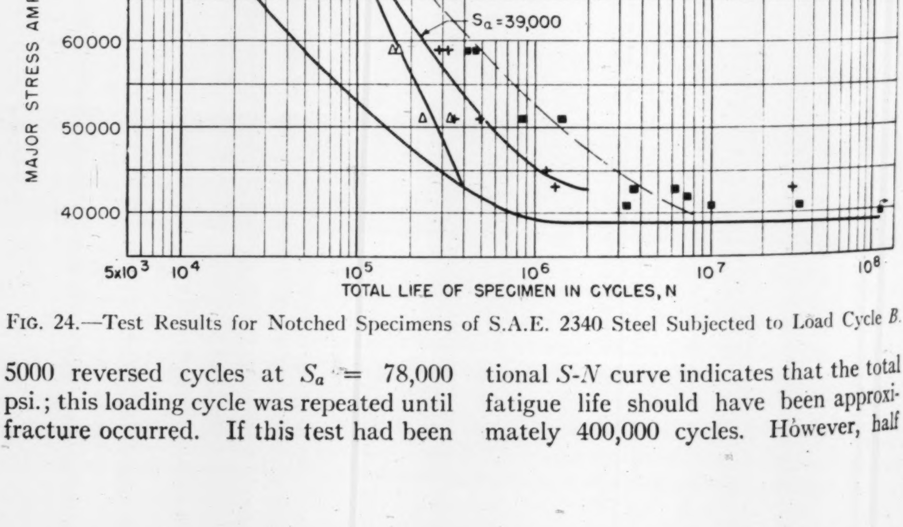


FIG. 24.—Test Results for Notched Specimens of S.A.E. 2340 Steel Subjected to Load Cycle *B*.

of the stress repetitions in the test represented by point *P* actually had amplitudes less than the endurance limit and thus might be assumed to produce no damage. If this assumption were valid, the *total* fatigue life should have been twice as great as that obtained for the *S-N* curve, or about 800,000 cycles, for a stress amplitude of 100,000 psi.

In Figs. 25 and 26 two dotted curves

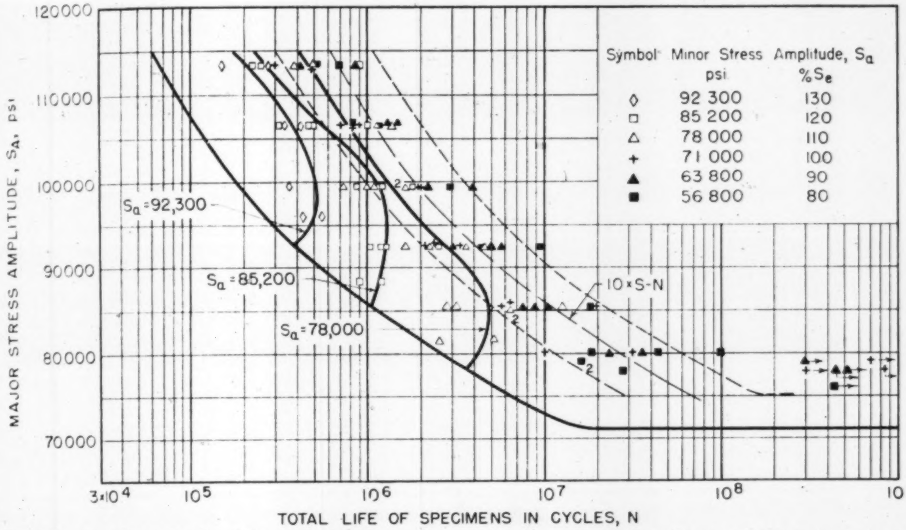


FIG. 25.—Test Results for Unnotched Specimens of S.A.E. 2340 Steel Subjected to Load Cycle *B*

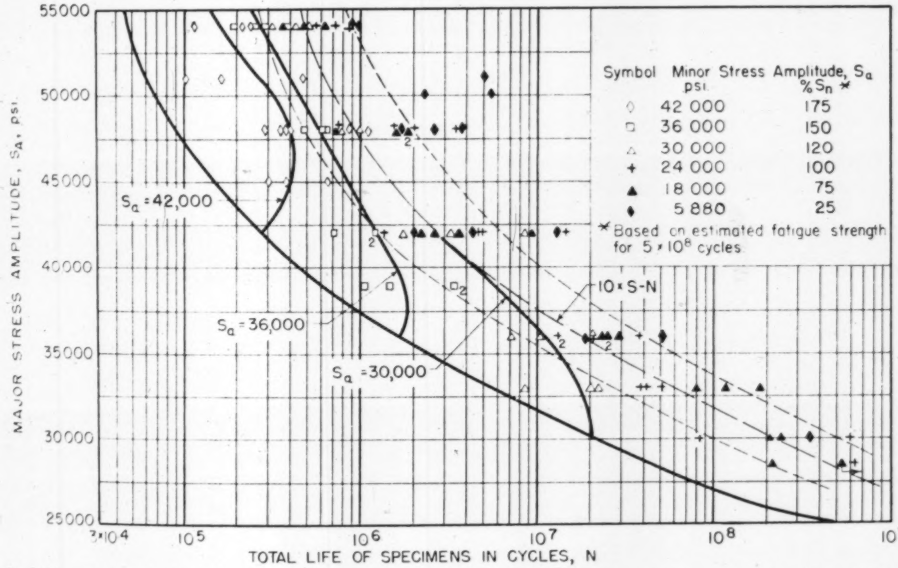


FIG. 26.—Test Results for Unnotched Specimens of 75S-T Aluminum Alloy Subjected to Load Cycle *B*.

are sketched in to represent the normal scatter bands of Figs. 12 and 14, but offset to the right by factors of ten for use with the 10 × S-N curve. Because of the statistical nature of fatigue life, these regions of normal scatter are useful for comparison with the results of the fluctuating load tests.

DISCUSSION OF RESULTS

Because of the large number of variables involved, the discussion of results has been sub-divided into several portions, each of which deals with the effects observed by altering a limited set of test conditions. The inherent scatter in fatigue life normally observed for like specimens under the same test conditions made it desirable to make duplicate tests to obtain consistent trends from the alteration of any single variable. With the limited supply of specimens available this was not possible in the preliminary tests on S.A.E. 4340 steel but was attempted in the tests of the other three metals.

The discussion is intended mainly to make comparisons of the effects on fatigue life produced by several different types of stress history, but it has been necessary in some instances to restrict the comments further to individual types of specimens or materials in those instances where generalizations of the behavior pattern did not seem obvious or warranted. The tentative results of the preliminary tests will first be discussed and will be followed by detailed analyses of the effects observed for load cycle B; a later section discusses certain observations of the effects noted for specimens retested after being subjected to various random stress histories. The final sections summarize briefly the results for the several materials and compare some of the results with the work of previous investigators.

Interchanging Initial Sequence of Applying the Major And Minor Stress Amplitudes:

In the data plotted in Figs. 16 and 17, certain differences in the life of specimens were observed when the stress history was begun at the minor stress amplitude rather than at the major stress amplitude (that is, the total number of cycles to failure was altered by starting the loading cycle at Q rather than at P in Figs. 2 and 5). The square symbols (Figs. 16 and 17) represent tests in which the minor stress amplitude was applied first, and the round symbols represent tests begun at the major stress amplitude.

At each level of major stress amplitude for which both sequences were employed the solid square symbols (with two exceptions) fell definitely to the right of the solid round symbols. Thus, when 5000 repetitions of the minor stress amplitude were applied before the first 5000 applications of the major stress amplitude longer life generally resulted. This increase in fatigue life was fairly definite when the major stress amplitude was either high or low (less than 10 per cent above the endurance limit) but the trend was not entirely convincing for intermediate values of the major stress amplitude (Fig. 16). A tendency for results to be somewhat different for these three general regions of the major stress amplitude (low, medium, and high) has been noticed also in other tests to be discussed in the following pages. Since the lower stress amplitudes were below the fatigue limit in all the tests for which these comparisons were made, the initial 5000 cycles of amplitude S_a represented an indeterminately small cycle ratio. The first 5000 cycles of the major stress amplitude was equivalent to a cycle ratio varying from about 10 per cent (when the major stress amplitude was at the top level of stresses on the S-N curve) to about $\frac{1}{2}$ of 1 per cent for stresses just above the fatigue limit.

Similar comparisons for load cycle *G* may be made in Figs. 16, 17, and 19, but the fatigue lives (represented by the open circles and open squares) did not fall in any definite pattern relative to each other. Thus, there was no consistent trend (either toward longer or toward shorter fatigue life) in cases for which load cycle *G* was initiated at the minor stress amplitude as compared with tests begun at the major stress amplitude. The approximate cycle ratio for the first group of peak stresses[5] was less than 5 per cent in any of the tests discussed here. Hence, one might expect that the damaging effect of the first group of peak stress cycles would be less noticeable than for stress histories such as load cycle *A* in which a larger cycle ratio was applied in the first group of peak stresses.

For load cycle *B* all tests were begun at the major stress amplitude, and no comparisons were made of the possible alteration in fatigue life that might be produced by starting the loading sequence at the minor stress amplitude.

Load Cycles A and G:

In general, load cycle *G* gave approximately the same fatigue life as load cycle *A* in tests using the same values of major and minor stress amplitudes. The results plotted in Figs. 16, 17, and 19 indicated similar behavior; for any given major and minor stress amplitudes the scatter and approximate mean values of fatigue life produced by load cycle *G* were comparable with the scatter and mean values of life produced by load cycle *A*. This inference that the gradually varying load cycle was as damaging to the specimen as the type *A* loading indicates that the small proportion of high stresses in the stress history *G* enabled damage to continue to be produced at the lower stresses.

In Fig. 20 (*a*) the stress amplitude in load cycle *G* was assumed to vary as a cosine curve with a period of 10,000 stress cycles. This representation is equivalent to converting the stress amplitudes to relative values on a scale in which S_a is represented by 0 and S_A is 100. By dividing the difference between the maximum and minimum stress into ten parts and determining the per cent of the load cycle during which each bracket of stress was effective, the distribution of Fig. 20*b* was determined. The total number of cycles for which the stress was between 90 and 100 (peak stresses) corresponds to 2060 stress cycles or 20.6 per cent of the loading cycle. Similarly, the relative stress amplitude was between 80 and 90 for 890 stress cycles or 8.9 per cent of the loading cycle, etc.

This type of stress history differs markedly from the curve *CDEF* in Fig. 20*b* which shows graphically the number of stress cycles applied at each level of stress amplitude in load cycle *A*; consequently it is surprising that fairly close agreement was obtained for number of cycles to fracture for these two different loading cycles. For load cycles *A* and *G* the influence of the minor stress amplitude on fatigue life was judged by comparing the cumulative life at the major stress amplitude with the corresponding life as represented by the ordinary *S-N* curve by use of the 2 × *S-N* curves.

It will be observed in Figs. 16 and 17 that for unnotched specimens of S.A.E. 4340 steel subjected to load cycles *A* or *G*, the points representing the total life fell short of the 2 × *S-N* curve for all values of the major stress amplitude that were more than 10 per cent above the fatigue limit. For load cycle *A* this was evidence that a certain degree of damage was developed at minor stress amplitudes of 78,000 psi. and 60,000 psi.; both these levels were definitely below the original fatigue limit and normally would not be expected to affect the fatigue life.

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[5] The "cycle ratio" is expressed in per cent of the expected life to the *S-N* curve at stress S_A. For load cycle *G* the "peak" stresses have been arbitrarily selected as those having an amplitude greater than that represented by point *B* in Fig. 20 as will be explained in the next section.

Notched specimens of S.A.E. 4340 steel (Fig. 19) exhibited considerable variation in fatigue life when the major stress amplitude was low; in general, the total life fell in the region of the curve 2 × *S-N* for both loadings *A* and *G*. Thus, no pronounced damaging or healing effect was produced by repetitions of the minor stress (understressing). The major stress amplitude apparently controlled the life of the notched specimens; failure occurred when the cumulative number of cycles of only S_A reached the *S-N* curve. This observation agrees with the first of Stickley's conclusions (7) that:

> "For tests (of 25S-T aluminum alloy) in which the greater number of cycles was at a stress below the endurance limit, the number of cycles applied at this stress apparently had no effect upon the fatigue life at the higher stress."

The study of *notched* specimens of S.A.E. 1045 steel subjected to fluctuating load cycles (plotted in Fig. 21) indicated that the fatigue limit was raised by the intermittent repetitions of a minor stress (S_a = 14,800 psi.) 20 per cent below the *original* fatigue limit. In determination of the original *S-N* curve there was very little scatter (Fig. 13); both the knee and horizontal portion of the curve (the fatigue limit) were quite definite. It seemed significant therefore that fracture did not develop in specimens subjected to loadings *A* or *G* with a major stress amplitude of 22,200 psi. Furthermore, with the major stress amplitude raised to 25,900 psi. (40 per cent above the original fatigue limit) a single specimen subjected to load cycle *A* withstood over 80 million repetitions of stress without failure.

Failure was produced, however, by load cycle *G* when the major stress amplitude was raised to 25,900 psi., (Fig. 21). Although this type of loading developed fewer repetitions of the maximum stress, so also were there fewer repetitions at the minimum level; in this instance, the amplitude of about two thirds of the stress cycles was above the ordinary fatigue limit.

A greater number of specimens were prepared for later tests, making possible somewhat more complete studies of S.A.E. 1045 steel. The data plotted in Fig. 22 for unnotched specimens provide comparisons of the relative total fatigue life resulting from each type of load cycle. Here again the average fatigue life for specimens subjected to load cycle *G* (represented by open circles) was approximately equal to (or fell within the same scatter band) as the data represented by the solid circles for load cycle *A*.

Thus, based on the frequency distribution of Fig. 20, the applications of lower levels of stress during 80 per cent of the load cycle combined with 2000 repetitions of the peak stress resulted in the same rate of damage as 5000 cycle groups of the same peak stress intermittently applied in load cycle *A*. Evaluating the effect of each level of stress in load cycle *G* (especially for those stresses below the fatigue limit) is made difficult by the gradual nature of the variation. Essentially there are at least 5000 different amplitudes of stress that may be visualized as having been applied during one loading cycle; this leads to uncertainties in determining which stress levels are of primary importance in controlling the fatigue life. These uncertainties were not so pronounced with loading *A*; however, even for load cycle *A* there was some doubt as to whether the data in Fig. 22 could adequately be interpreted as following the 2 × S-N curve, since some of the points fell close to the ordinary S-N curve.

Load Cycle B:

Early in the experimental program, it was found that load cycle B tended to accentuate the effect of the lower frequency of peak stresses in influencing the somewhat longer fatigue life. Hence, the majority of tests employed this type of loading in which 10 per cent of the stress cycles were applied at a high stress (major stress amplitude) and 90 per cent of the cycles were applied at a lower stress (minor stress amplitude). In order to minimize the confusion arising from the many variables involved, the following discussion has been divided into sub-sections in accordance with the kind of material and type of specimen considered.

(*a*) *S.A.E. 4340 Steel.*—For unnotched specimens of S.A.E. 4340 steel, two levels of the minor stress amplitude were chosen (78,000 psi. and 60,000 psi.), and the results obtained are plotted in Figs. 16 and 17, but for direct comparison the data from the two sets of tests in which only load cycle B was employed are replotted in Fig. 18. The curve marked S_a = 78,000 psi. was drawn as an approximate average through the solid points for tests in which the minor stress amplitude was 78,000 psi. The corresponding average curve for S_a = 60,000 psi. was found to be similar in shape, but in general the total fatigue life represented for all levels of the major stress amplitude above 96,000 psi. was slightly more than twice the life indicated by the curve for S_a = 78,000 psi.

The two curves in Fig. 18 show three definite tendencies for *unnotched* specimens of S.A.E. 4340 steel: (*a*) a new "fatigue limit" was indicated at about 96,000 psi., or 10 per cent higher than the fatigue limit for virgin specimens; (*b*) damage done by repetitions of the minor stress amplitude (as judged by the reduction of fatigue life at the major stress amplitude) was greatest when the major stress amplitude was about 100,000 psi., that is, just above the new fatigue limit; (*c*) the relative damaging effect, produced by the minor stress amplitude (either 78,000 psi. or 60,000 psi.), was progressively smaller for increasing values of the major stress amplitude. The damage due to repetitions of stress S_a = 60,000 psi. was reduced to zero at S_A = 115,000 psi.; for higher levels of the major stress longer life was achieved than would have been expected. Similarly, the curves marked 10 × S-N and S_a = 78,000 psi., if extrapolated would intersect at S_A = 129,000 psi. It might thus be expected that zero damage would result from repetitions of the minor stress of 78,000 psi. when S_A was approximately 129,000 psi. ("negative damage" or strengthening might appear for S_A greater than 129,000 psi.).

In spite of the normal scatter in fatigue life plotted in Fig. 18 the evidence seems quite definite that a damaging effect (a reduction of fatigue life) did result from the repetitions of an "understress" (S_a) below the fatigue limit. Longer fatigue life of unnotched specimens resulted when S_a was reduced from 78,000 to 60,000 psi.

The total life of *notched* specimens of S.A.E. 4340 steel subjected to load cycle B fell along the 10 × S-N curve in Fig. 19 indicating that (as in the case of the load cycle A) the repetitions of the minor stress amplitude had no effect (failure occurred when the cumulative number of cycles at only the major stress reached the S-N curve). Contrary to the behavior noted for unnotched specimens, no pronounced increase in the fatigue limit was noted in tests of notched specimens of S.A.E. 4340 steel.

(*b*) *Unnotched Specimens of S.A.E. 1045 Steel.*—As indicated in the legend of Fig. 23, five groups of *unnotched* specimens of S.A.E. 1045 steel were tested, each with a different value of minor stress amplitude in load cycle *B*. An average curve for each group was sketched through the points plotted at the levels of major stress amplitude employed. In this diagram it was noted that three tendencies were exhibited by the curve for S_a = 45,000 psi., namely, (*a*) an increase of about 5 per cent in the fatigue limit; (*b*) pronounced damage (decreased fatigue life) for major stress amplitude between 53,000 and 68,000 psi.; (*c*) a slight (perhaps insignificant as compared with the 10 × *S-N* curve) lengthening of life for S_A greater than 70,000 psi. As judged by comparison of the fatigue life with the 10 × *S-N* curve the relative amount of damage done by repetitions of the minor stress was greatest when the major stress was about 58,000 psi. and was decreased for successively higher values of the major stress; "negligible damage" or even slightly increased fatigue life resulted when the major stress amplitude was raised above 68,000 psi. It may also be seen that for a minor stress amplitude of 50,000 psi. (at or barely above the original fatigue limit) the fatigue life obtained was in general decreased to about three fourths the life obtained for a minor stress amplitude of 45,000 psi. However, the two curves representing average life for S_a = 50,000 psi. and S_a = 45,000 psi. had the same general characteristics.

For minor stress amplitudes of 55,000 psi. or 60,000 psi., the total fatigue life was a function of the magnitudes of both the major and minor stress amplitudes, S_A and S_a. Higher values of S_A reduced the fatigue life; similarly the fatigue life was shorter when S_a was increased from 55,000 psi. to 60,000 psi. Failure occurred before the cumulative number of cycles at *either* the major or the minor stress amplitudes reached the *S-N* curve.

A surprisingly long fatigue life was observed in Fig. 23 with the minor stress amplitude 65,000 psi. When alternated with major stress amplitudes up to 75,000 psi. the total life was comparable with the abscissa to the *S-N* curve for a stress of only 65,000 psi. (that is, the fatigue life was *as long* as if all stresses had been applied at only 65,000 psi.). However, this observation may not be considered significant since it is based on tests of only a few specimens.

(*c*) *Notched Specimens of S.A.E. 2340 Steel.*—As shown in Fig. 24, repetitions of a minor stress below the fatigue limit did not have an apparent effect on the fatigue life of *notched* specimens of S.A.E. 2340 steel subjected to load cycle *B*. The data (represented by square symbols) fell along the 10 × *S-N* curve; hence, the cumulative number of cycles of the major stress should have been sufficient to cause failure alone. There was some indication of a slight increase in fatigue limit, but it was considered to be insignificant.

The average curves in Fig. 24 indicate that for minor stresses at or above the fatigue limit (39,000 psi.) the total fatigue life was influenced by the magnitudes of both S_A and S_a. The fatigue life for S_a = 43,000 psi. was shorter than for S_a = 39,000 psi. For either of these values of the minor stress amplitude, the total fatigue life was gradually decreased as the value of the major stress amplitude was successively increased.

(*d*) *Unnotched Specimens of S.A.E. 2340 Steel.*—In Fig. 25 it may be observed that when the minor stress amplitude, S_a, was *at or below* the fatigue limit of 71,000 psi. an indefinitely large number of applications of stresses up to 78,000 psi. (as S_A in load cycle *B*) could be withstood without failure occurring. This was equivalent to raising the fatigue limit about 7000 psi. or 10 per cent. A healing effect must have been developed by each 9000 repetitions of minor stress to compensate for the damage done by each 1000 applications of major stress somewhat higher than the original fatigue limit.

In contrast with this behavior the healing produced by intermittent understressing was not sufficient to offset the damage produced by major stress amplitudes greater than 79,000 psi.; failure occurred at these higher values of S_A corresponding to a total fatigue life approximately equal to ten times the life represented by the *S-N* curve at that stress. That is, the plotted points generally fell within the scatter band for the ordinary *S-N* curve which is represented in Fig. 25 by the dotted curves on either side of the 10 × *S-N* curve.

For the three groups of tests in which the minor stress amplitude was 71,000 psi. or less, the fatigue lives overlap with little definite order.[6] From these observations it would appear that the major stress amplitude determined completely the total fatigue life in the type *B* loading cycle when the major stress was greater than 80,000 psi.; that is, failure occurred in the unnotched specimens of S.A.E. 2340 steel when the cumulative number of cycles of only S_A reached the *S-N* curve and no significant change in fatigue life occurred when the minor stress amplitude was varied over this range of values of understress.

In the groups of experiments for which the minor stress amplitude S_a was *above* the fatigue limit, the fatigue life could not be readily predicted from knowledge of the ordinary *S-N* curve. Figure 25 shows that for S_a = 78,000 psi. the average life of unnotched specimens of S.A.E. 2340 steel with a major stress amplitude of 85,200 psi. was approximately 480,000 cycles; this life was greater than the normal number of cycles to the *S-N* curve at a stress amplitude of only 78,000 psi. With S_a raised to 85,200 psi. the total life to failure was approximately 110,000 stress cycles whether the stress amplitude was constant at 85,200 psi. or alternated in load cycle *B* between 85,200 psi. and a major stress as high as 99,400 psi. Similarly, for S_a = 92,300 psi., the fatigue life was at least 38,000 cycles for S_A at any level from 92,300 psi. to 106,500 psi. (more than 15 per cent above). Thus, even though 10 per cent of the cycles were applied at higher values of stress, the life in these tests was at least as long as though all repetitions of stress were at the level of the *lower* stress amplitude.

Minor stress amplitudes above the fatigue limit would be expected to have a pronounced damaging effect since sufficient repetitions at any one such level of overstress would cause failure The results shown in Fig. 25 indicated this to be true *except*, as noted above for those cases in which the difference between the major and minor stress amplitudes was only 10 or 15 per cent.

(*e*) *Unnotched Specimens of 75S-T Aluminum Alloy.*—Applications of a very low minor stress amplitude in load cycle *B* increased the relative life of unnotched specimens of 75*S-T* aluminum alloy for all levels of major stress amplitude. For example, in Fig. 26 the points representing fatigue life for S_a = 5880 psi. fell to the right of the 10 × *S-N* curve. Thus, these specimens withstood more applications of the higher stress amplitude than normal when 1000 cycle blocks of the major stress were alternated with 9000 cycle repetitions of the low amplitude stress. Since the 75*S*-*T* aluminum alloy did not have a definite fatigue *limit*, it is sometimes thought that even such low values of stress might cause fatigue damage if repeated a sufficient number of times. There was no indication in Fig. 26 of a decrease in fatigue life caused by low levels of minor stress amplitude, 24,000 psi. or below. The trend apparently is in the other direction since a substantial majority of points plotted for minor stress amplitudes of 24,000 psi. or 18,000 psi. also fell to the right of the 10 × *S*-*N* curve, either within or slightly beyond the normal scatter band for the ordinary *S*-*N* curve which is outlined by dotted lines.

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[6] There was a slight tendency for the life with S_a = 71,000 psi. to fall to the left of those points obtained from the two groups tested with S_a = 63,000 psi. or S_a = 56,800 psi.

The low stress amplitude of 5880 psi. was only 25 per cent of the fatigue strength based on 5 × 10^8 cycles, and therefore might be considered to approach a condition of rest. Although early investigators (15) discounted the possibility of recovery from fatigue damage by rest periods, some relaxation of damage produced by the repetitions of high stress may have been achieved (16) during the repetitions of low amplitude minor stress.

Higher levels of stress have a greater capacity for cold working the metal than do lower stress levels; hence, if the increased life were due to cold working produced during the applications of the lower stress one would expect a greater increase in life when the minor stress amplitude was raised to values near the fatigue strength. However, this was not the case; the data in Fig. 26 indicated that the fatigue life was in general decreased slightly by raising the level of the minor stress amplitude from 5880 psi. to 18,000 psi. or 24,000 psi. The rather abrupt flattening off of the static stress-strain curve for loads above the yield strength (Fig. 10) was an indication that for this aluminum alloy the range of strain-strengthening by plastic deformation was rather narrow. The true "fracture stress," found by dividing the load at rupture by the actual reduced area, was only about 117,000 psi. Thus, the relatively narrow range of possible strengthening by plastic action may have limited the extent to which cold working influenced the fatigue strength.

It may also be observed in Fig. 26 that repetitions of a minor stress of 30,000 psi. had no appreciable effect on the total fatigue life for values of major stress greater than 40,000 psi. since the total life corresponded with the 10 × *S*-*N* curve. In contrast to this behavior, however, as the difference between major and minor stress amplitudes was decreased, both stress levels had a damaging influence on the fatigue life.

For values of minor stress amplitude of 36,000 or 42,000 psi., the average curves indicated the following characteristics: (*a*) For levels of major stress amplitude only moderately above the minor stress amplitude (10 to 20 per cent above S_a) the total life was as long or longer than that represented by the *S*-*N* curve for a stress as low as the minor stress amplitude; (*b*) When the difference between the two levels of stress amplitude was greater than these limits, the fatigue life was dependent upon both S_a and S_A; a shorter life was obtained by increasing the magnitude of either the major or the minor stress amplitude.

Fatigue Life After Previous Stress History:

The open circles plotted in Figs. 11 to 15 represent the fatigue life in a retest for specimens that had not failed in a previous fatigue test. The effect of the previous stress history may be judged by comparing the fatigue life in the retest (employing repeated stress of constant amplitude) with the normal life of virgin specimens as represented by the ordinary *S-N* curve and scatter band. The behavior in the retest apparently depended on the magnitude of the retest stress. When the retest stress was high relative to the fatigue limit for virgin specimens, the retest life seemed to be equal to the expected life for virgin specimens subjected to the same cyclic stress. On the other hand, when the retest stress was within 10 or 20 per cent of the fatigue limit, the retest life seemed to be considerably longer than the normal life of virgin specimens.

TABLE V.—FATIGUE LIMITS AS INFLUENCED BY STRESS HISTORY.

	S.A.F. 4340 Steel	S.A.E. 1045 Steel		S.A.E. 2340 Steel	
	Unnotched	Notched	Unnotched	Notched	Unnotched
Virgin material, Fatigue limit (S_e), psi.	87 000	18 500	49 500	39 000	71 000
Load cycle *B*					
Fatigue limit, psi.[a]	96 000	26 000	54 000	42 000[b] 40 000[c]	78 000
Increase over S_e, per cent	10	40	9	8 3	10
Load cycle *A*					
Fatigue limit, psi.[a]	87 000[c]	26 000	54 000		
Increase over S_e, per cent	0	40	9		
After miscellaneous prestressing,					
Fatigue limit, psi.	100 000	23 000	53 000[d]	42 000[d]	75 000[d]
Increase over S_e, per cent	15	24	7	8	6

[a] The fatigue limit for a fluctuating load cycle is listed as the maximum value of major stress amplitude that did not produce failure after 10 million cycles when alternated with minor stresses of lower value.

[b] Estimated for $S_a = 39,000$ psi.

[c] For $S_a = 31,000$ psi.

[d] Estimated by extrapolation.

In order to distinguish between the types of stress history for the retest points plotted in Fig. 11, the letters *A*, *B*, *C*, and *G* have been inserted to indicate the types of loading cycle employed prior to the retest. Two or more letters have been used in some instances to indicate the sequence of loadings employed on a specimen that did not fail in two or more previous tests. From the complete prestress histories for these specimens as listed in Table IV it will be noted that their previous stressing differed in type of loading, amplitudes of stress, and number of cycles or prestress applied. It can be seen from the data for unnotched specimens of S.A.E. 4340 steel in Fig. 11 that for retest stresses higher than 100,000 psi. (more than 15 per cent above the fatigue limit) all points fell within the normal scatter band on both sides of the *S-N* curve, whereas for retest stresses below 100,000 psi. no specimen with a previous stress history failed. At 100,000 psi. there was a wide scatter in life with failures occurring at as few as 240,000 cycles, while other specimens withstood 30 to 100 million repetitions of stress without failure.

This stress of 100,000 psi. thus constituted a type of "fatigue limit" for specimens with a previous stress history which, after many millions of cycles in the retest, did not fracture. This "retest fatigue limit" was 15 per cent higher than the fatigue limit of 87,000 psi. for virgin specimens. One specimen (W 67, Table IV) was subjected to three successively higher stages of prestressing and exhibited considerable strengthening as a result of this "coaxing" process. At the conclusion of the test there was no evidence of fatigue damage to the specimen when a bearing failure in the testing machine bent the specimen during the third retest at a stress of 105,000 psi. (20 per cent above the fatigue limit). It had already withstood 3,869,000 repetitions of stress, or 17 times the fatigue life expected for virgin specimens subjected to the same stress.

Although the magnitudes of the apparent new fatigue limits resulting from a previous stress history were not definitely established for the different steels tested, there were indications that if slightly lower retest stresses had been chosen an indefinitely long fatigue life would have resulted at stresses above the virgin fatigue limit. Similarly, it was pointed out in the preceding discussion of fluctuating load cycles that an apparent increase in fatigue limit was obtained under certain conditions for tests with load cycles *A* and *B*. Rough approximation of the apparent raised fatigue limits obtained after miscellaneous types of prestressing or obtained in tests employing load cycles *A* and *B* have been listed in Table V for comparison with the fatigue limits of virgin specimens of the same steels. Some of the values in Table V represent estimates obtained by extrapolating the trends appearing in the data available. These approximate values seem consistent with the other results but should be regarded only as estimates which may not be completely reliable.

Comparison With Previous Work:

Previous investigators (**4**, **5**, **6**, **17**, **18**) have found that the fatigue limit of a ferrous metal apparently is not a fixed quantity but can be either increased or decreased by a previous stress history. In the present tests, the periodic applications of an overstress, S_A, in a given test may likewise have progressively reduced the fatigue limit; hence, in the latter stages of some of the tests, levels of stress, S_a, below the original fatigue limit, probably represented actual overstresses.

Bennett (**5**), Kommers (**4**), and Lea (**18**) also showed that an increase in fatigue limit resulted from certain types of understressing produced by subjecting specimens to one extended period of prestressing. There were indications in the present tests that similar results were obtained from repetitions of the strengthening level of stress (in this case S_a) when applied intermittently with groups of definite overstresses. In some instances the healing effect produced in each loading cycle by the repetitions of the minor stress compensated for the damage done by applications of a major stress somewhat higher than the fatigue limit for virgin specimens.

For the purpose of predicting fatigue failure of members subjected to varying stresses, Miner (**10**) proposed that the cumulative damage in fatigue be computed by adding the cycle ratios at each stress, based on the assumption that fracture should occur when the cumulative total equals unity. This hypothesis may be expressed by the equation:

$$\frac{n_1}{N_1} + \frac{n_2}{N_2} + \frac{n_3}{N_3} + \cdots = \Sigma \frac{n}{N} = 1 \ldots \quad (1)$$

where:

n_1 = number of cycles applied at stress S_1,

N_1 = number of cycles to *S-N* curve at stress S_1,

n_2 = number of cycles applied at stress S_2,

N_2 = number of cycles to *S-N* curve at stress S_2 etc.

For example, by applying this equation to the data of Fig. 17 obtained for S_a = 90,000 psi. and S_A = 110,000 psi. using load cycle A, the following results were obtained:

$S_1 = 110{,}000$ psi. $S_2 = 90{,}000$ psi.
$n_1 = 58{,}000$ psi. $n_2 = 58{,}000$ psi.
$N_1 = 136{,}000$ psi. $N_2 = 1{,}050{,}000$ psi.

$$\frac{n_1}{N_1} + \frac{n_2}{N_2} = \frac{58{,}000}{136{,}000} + \frac{58{,}000}{1{,}050{,}000} = 0.48$$

Hence, the cumulative cycle ratio $\sum \frac{n}{N} = 0.48$ and does not agree with Eq. 1.

With the same major and minor stress amplitudes as used above, the specimen subjected to the cycle G failed at a total of 142,000 cycles. An approximate method of adding up cycle ratios in load cycle G was provided by dividing the stress amplitudes into ten stress brackets as shown in Fig. 20. The following results were computed on that basis:

Stress Bracket	Stress, S, psi.	Cycles Applied, n, psi.	Cycles to Failure, n, psi.[a]
1	109 000	29 200	150 000
2	107 000	12 600	185 000
3	105 000	10 500	227 000
4	103 000	9 450	286 000
5	101 000	9 400	340 000
6	99 000	9 400	440 000
7	97 000	9 450	510 000
8	95 000	10 500	630 000
9	93 000	12 600	770 000
10	91 000	29 200	950 000

[a] Expected life to produce failure if run at constant stress; values obtained from ordinary S-N curve.

By substituting these values in Eq. 1, a value for $\sum \frac{n}{N} = 0.47$ was obtained. In analysing the results of the experiments the data from a number of tests were substituted in Eq. 1 and values of the cumulative cycle ratio determined as illustrated above. A wide spread in these values was found, however, ranging rather arbitrarily from 0.18 to more than 23.0 with only a small proportion giving the assumed result of $\sum \frac{n}{N} = 1$. It was therefore concluded that Eq. 1 did not adequately express the variations in fatigue life obtained from the present experiments employing fluctuating stress amplitudes. The data of both Bennett and Kommers (5, 4) have also indicated that this equation was not accurate since the damage produced by a given cycle ratio at one stress is not equal to the damage produced by the same value of cycle ratio at another stress. In their tests, greater equivalent damage was observed at a lower test stress after a given cycle ratio at a high prestress than was evident at the high test stress after prestressing for the same cycle ratio at the lower stress. This fact is illustrated in Fig. 7 by the difference in results obtained from interchanging the prestress and test stress levels. The dashed line at 45 deg. to the axes represents the condition for per cent damage equal to per cent cycle ratio as would be the case for the assumption introduced by Miner. From these two curves it is evident that the sequence of stressing is an important factor in the determination of cumulative damage in fatigue.

Cycle ratio *versus* damage curves of the type reported by Bennett (5) were not determined for the metals discussed in this paper. The *repeated* fluctuations of stress amplitude employed in these studies cannot be adequately represented by simple damage curves (Fig. 7) for each pair of stress levels; the question would immediately arise as to which of these two stresses to call the "prestress" and which the "test stress." Since cumulative damage in fatigue is not linearly related to the magnitude of stress nor to the number of stress cycles, it becomes difficult to formulate any simple functional relation to express the deleterious (or beneficial) effects of a stress history. Simple principles of superposition are not adequate for analysis of phenomena such as fatigue damage which are related to the continuous structural changes taking place to varying degrees of severity at different stress levels and cycle ratios (16).

General Summary:

It has been pointed out that when the minor stress amplitude was *equal to or less than the original fatigue limit* in tests of S.A.E. 1045 steel with load cycles A or B, three effects were noted: (*a*) the fatigue limit was raised; (*b*) accentuated damage was produced for values of S_A immediately above the new fatigue limit; and (*c*) the relative fatigue life (in comparison with that predicted from the S-N curve) was increased for tests employing higher values of major stress amplitude. A similar behavior was indicated in tests of *unnotched* specimens of S.A.E. 4340 steel.

In the few tests of *notched* specimens of S.A.E. 1045 steel and in the groups of *unnotched* specimens of S.A.E. 2340 steel an increase in fatigue limit was the only one of these three tendencies observed. For *notched* specimens of S.A.E. 4340 steel none of these three effects were apparent, whereas these trends were evident for *notched* specimens of S.A.E. 2340 steel only when the lower stress amplitude was equal to the original fatigue limit; however, a slight increase in fatigue life was also indicated when S_a was 80 per cent of the original fatigue limit.

In general, for the steels investigated the larger number of repetitions of an understress (below the fatigue limit) in load cycle B had no pronounced effect on the fatigue life if the major stress amplitude was sufficiently high. For the 75S-T aluminum alloy, minor stress amplitudes between 75 and 100 per cent of the fatigue strength had no significant effect on the fatigue life observed for a wide range in values of major stress amplitude; conversely, however, lowering the minor stress amplitude to only 25 per cent of the fatigue strength resulted in a slight increase in fatigue life.

For test conditions in which the minor stress amplitude was an overstress and the difference between the major and minor stress amplitudes was small, an abnormal increase in fatigue life was produced which indicated that the material was able to develop strengthening effects to prolong the total life to a number of cycles as great as though all stresses had been at the lower level. This paradoxical behavior was evident in the data from the three metals subjected to these test conditions.

Though this curious prolongation of fatigue life would not at first seem logical, it is probably further evidence of the same phenomena that produce the increased life observed in numerous tests involving understressing (see references (2 to 6) inclusive, and (15 to 20) inclusive). Several investigators have demonstrated that by repeatedly stressing a specimen for a few million cycles just below the fatigue limit, and then successively increasing the load by small increments with a large number of stress cycles at each increment ("coaxing"), the fatigue limit is raised appreciably and the life at the higher stress levels may be astonishingly long as compared with the virgin metal. Moreover, Moore and Jasper (19), Kommers (2), and Bennett (5) have found that it is possible to take metal that has been damaged by previous overstressing and to repair the damage by understressing or "coaxing" to restore the fatigue limit to, or even increase it above, the original fatigue limit for the virgin metal.

Of particular interest in this process is the observation that the "coaxing" to be effective must be accomplished with relatively small increments of the successively increasing stress. This is consistent with the results of the present investigation which indicated an increased fatigue life for conditions in which the stresses were periodically alternated between minor and major stress amplitudes that did not differ in magnitudes by a large amount. Moreover, the mechanism leading to this strengthening effect apparently was operative even for cases in which *both* major and minor stresses were above the fatigue limit, whereas previous investigators have usually resorted to initial applications of stresses at or *below* the fatigue limit to produce similar "healing" effects. However, for cases in which the major stress amplitude was considerably greater than the minor stress amplitude the fatigue life was not in general increased; similarly, the "coaxing" process is not effective in increasing the fatigue life if large increments are used between subsequent values of the successively increasing stress.

The results of a considerable number of retests of notched and unnotched specimens of the three steels after miscellaneous types of prestressing fit consistently into two general categories as follows: (*a*) specimens with various types of stress history that were retested at a stress amplitude up to about 10 or 15 per cent above the fatigue limit of virgin specimens were characterized by a marked increase in fatigue life (in many cases indefinitely long); (*b*) specimens subjected to a retest at a higher stress exhibited a life comparable with that of the virgin specimens.

This behavior is consistent with the comparisons made above with respect to the "coaxing" process. In these retests it was again evident that if the previous stress history was accomplished at stresses not too greatly different from the new value of the (higher) test stress, an effect similar to "coaxing" resulted that became evident as a pro'ongation of fatigue life. However, no effect of "coaxing" was apparent in influencing the life of specimens retested at a stress considerably above the level of the stresses developed in the previous stress history.

CONCLUSIONS

This investigation comprised studies of the effect on fatigue life produced by several types of stress history in which the amplitude of stress was varied at regular intervals between two predetermined values. Both notched and unnotched specimens of small size were tested in rotating-beam fatigue machines; the majority of data were obtained with a loading cycle in which 1000 cycles of a high stress amplitude were repeatedly alternated with 9000 cycles of a lower stress amplitude. As a result of this study the following conclusions seem justified, as generalizations representative of the majority of test conditions involved:

1. The fatigue limit for a ferrous metal is not a definite quantity but may be altered by a previous stress history. In general, repetitions of an understress alternated with repetitions of a stress 10 to 20 per cent above the original fatigue limit resulted in a marked increase in fatigue life that may be interpreted as an increase in fatigue limit.

2. Specimens retested after being subjected to any of a number of different stress histories involving a large number of cycles of prestress consistently exhibited one of two general types of behavior: (*a*) retests at a stress amplitude up to about 10 or 20 per cent above the original fatigue limit were characterized by a marked increase in fatigue life; (*b*) specimens retested at high levels of stress exhibited a life comparable with that of virgin specimens.

3. The relative fatigue life (as com-

pared with the *S-N* curve) was influenced by intermittently applied repetitions of an *understress* but also depended on the magnitude of the major stress which was alternated with the understress. For cases in which the major stress amplitude barely exceeded the increased fatigue limit described above, an accentuated damage was observed (that is, the number of stress cycles sustained at the major stress was appreciably smaller than that predicted by the ordinary *S-N* curve). For extremely high values of major stress amplitude the total fatigue life was approximately that predicted by assuming failure would occur when the cumulative number of cycles of stress at only the major stress amplitude reached the *S-N* curve.

4. With minor stress amplitudes below the fatigue strength, the large number of repetitions of understress in load cycle *B* had little effect on the total fatigue life of specimens of S.A.E. 2340 steel of 75*S-T* aluminum alloy. In contrast with this behavior, accentuated damage seemed to be produced in S.A.E. 1045 and 4340 steels when repetitions of a minor stress below the fatigue limit were alternated with intermediate levels of major stress amplitude. Periodic repetitions of an extremely low understress (only one fourth of the fatigue strength based on 5×10^8 cycles) resulted in a slight increase in fatigue life for unnotched specimens of the 75*S-T* aluminum alloy.

5. With minor stress amplitudes above the fatigue limit (overstresses) and with the magnitude of the major stress amplitude only slightly greater than the minor stress amplitude, the total fatigue life was frequently found to be practically the same as though all stresses had been applied at the lower stress level; however, for increased values of major stress amplitude, fatigue failure generally occurred before the cumulative number of cycles at *either* the major or the minor stress amplitude reached the ordinary *S-N* curve.

Acknowledgments:

This investigation has been conducted by members of the staff of the Department of Theoretical and Applied Mechanics as a part of the work of the Engineering Experiment Station of the University of Illinois in cooperation with the Office of Naval Research, United States Navy (**14, 20**), under Contract N6-ori-71, Task Order IV, Project NR-031-005. Acknowledgment is also due Mr. S. W. Sandberg and Mr. D. P. Protzman, Student Assistants who aided in preparation of illustrations.

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DISCUSSION

MR. G. W. STICKLEY[1] *(presented in written form)*.—The tests that have been described in this paper concerning the effects of fluctuating cycles of stress upon fatigue life are very interesting. The data help toward a better understanding of conditions that are encountered in service, which rarely are as simple as in conventional tests.

It would be interesting to know whether the authors made any determinations of residual stress conditions in the specimens. While it seems quite likely that any conditions of residual stress that may have been present did not have any large effect on the results of the fatigue tests, still the effect may have been measurable. This effect could be favorable or unfavorable, depending to some extent upon whether the residual stresses were tensile or compressive and upon their distribution.

It is indicated in Table II of the paper, that the Brinell hardness value of the 75 S - T 6 aluminum alloy was determined using a 3000-kg. load, the same as in the tests of the steels. The hardness of aluminum alloys and other non-ferrous metals, however, usually is determined using a 500-kg. load (see A.S.T.M. Method E 10 - 27[2]). If this smaller load had been used, the Brinell hardness number would have been appreciably lower than 178.5, probably about 155.

MR. R. E. PETERSON.[3]—I would like to point out that this paper represents work in a field of considerable interest to designers. For example, it has not been found practical to design automobile and railway axles and other related parts so that all of the variable stresses do not exceed the endurance limit.

As Almen has pointed out, the life of a rear end automobile axle gear at full torque in low gear is of the order of 30 to 75 miles of car travel. Such severe loading is only rarely encountered in service, and then only momentarily.

Some years ago, Westinghouse made measurements of axle stress on electric locomotives during operation. Some of the stresses were below 10,000 psi., and the stresses varied up to 22,000 psi. The problem, then, is to try to take account of this spectrum of stresses in design.

We have been using the following (Shamberger-Langer) formula:

$$M = \frac{1}{\Sigma(P_n/C_n)}$$

where: M = number of miles to failure,
P = number of cycles per mile at a given stress level, and
C = number of cycles at a stress level corresponding to P.

In the application of this formula we have used 12 stress levels at 1000 psi. intervals, and as indicated above this results in the summation of 12 terms in the denominator.

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[1] Assistant Chief, Mechanical Testing Div., Aluminum Research Labs., Aluminum Company of America, New Kensington, Pa.

[2] Standard Method of Test for Brinell Hardness of Metallic Materials (E 10 - 27), 1946 Book of A.S.T.M. Standards, Part I-A, p. 710, Part I-B, p. 308.

[3] Manager, Mechanics Dept., Westinghouse Research Labs., Westinghouse Electric Corp., East Pittsburgh, Pa.

While we feel that the above formula has given us reasonable results, we know that it is not exact, since it corresponds to the 45-deg. line shown in several figures of the paper.

Work of the kind being carried out by Mr. Dolan and his associates will be helpful in arriving at a more precise basis for combining effects at various stress levels.

MESSRS. T. J. DOLAN, F. E. RICHART, JR., AND C. E. WORK (*authors' closure*).—In answer to Mr. Stickley's question, the fatigue specimens of necessity were rather small and no suitable means were available for making an accurate analysis of the residual stresses existing prior to the test. However, it is probable that the relatively high temperatures to which the steel specimens were subjected during the tempering would have removed the major portion of the residual stresses existing in the material prior to the final machining operations. Care was taken in the final machining to avoid heating or excessive rates of stock removal that might lead to further development of residual stress.

In all cases an attempt was made to prepare like specimens, which were then compared on the basis of relative fatigue life with fluctuating load cycles as contrasted with the life when subjected to constant stress amplitudes (as represented by the conventional *S-N* curve). Thus, even if residual stresses were present to some degree in the specimens, the comparisons of relative fatigue life should still be valid though the actual magnitude of stress existing in the specimens would be slightly different from the computed values.

For convenience, the Brinell hardness readings of the 75S - T alloy were made with the 3000-kg. load as indicated in the table. The 75S - T is one of the harder aluminum alloys, and the size of the indentation was not troublesome. Since the hardness readings were regarded as incidental measurements, it was not felt important to change to the 500-kg. load, which of course is more commonly employed in the hardness tests of non-ferrous metals, as Mr. Stickley points out. However, subsequent readings indicate the Brinell hardness with the 500-kg. load to be 158.

Mr. Peterson's discussion brings out the important aspect of our need for further information of the type presented in the paper. The designers of many types of machines (including aircraft) are faced with a difficult problem in trying to decide what effect the peak stresses and the frequency of incidence of various levels of stress will have on the fatigue life. The stress developed by nearly all parts such as axles, aircraft wings, springs, etc., fluctuates not through a sinusoidal cycle but over a rather complex stress history. There is no generally accepted rational manner of formulating in the laboratory a simple test condition that will evaluate the ability of the metal to withstand this random type of stress variation. It was the purpose of the experiments reported in the paper to examine the fatigue behavior under the simplest types of stress fluctuation involving only two stress levels. However, even this simple fluctuation produced variations in fatigue life that could not be predicted from the data contained in the conventional *S-N* diagram.

The formula proposed by Mr. Peterson is based on the assumption that fatigue damage at stresses above the fatigue limit is proportional to the cycle ratio at each level of imposed stress. Since the data of Bennett and Kommers (and many of the results presented in this paper) indicate that the proportionate fatigue damage is not directly related to the cycle ratio, the formula is necessarily somewhat in error. However, for those cases in which the stresses fluctuated between levels above and below the fatigue limit (See Figs. 19 and 24), the fatigue life for notched specimens of SAE 4340 and 2340 steels was comparable with the life that one might predict from the *S-N* curve by counting only the cycles of overstress. On the other hand, the data in Figs. 18, 22, and 25 indicate that repetitions of an understress did affect the fatigue life of unnotched specimens of the three steels tested. Hence, it appears probable that until more knowledge is available of the exact behavior of the material under fluctuating fatigue stresses, it is not possible to formulate an accurate rational procedure for predicting fatigue life. Until such time as this knowledge becomes available, it will continue to be necessary to use approximating relationships as the only means of supplying the designer with a crude approach to guide him in the selection of and proportioning of useable machine components.

THE EFFECTS OF METALLIZING PROCEDURES ON THE FATIGUE PROPERTIES OF STEEL*[1]

BY W. LEE WILLIAMS[2]

SYNOPSIS

This paper presents the results of part of an investigation to determine the effects of metallizing and attendant methods of surface preparation on the flexural and torsional fatigue properties of steel. The four conventional methods of surface roughening, namely, electric bonding, grit blasting, rough threading, and grooving and knurling, have been investigated. The use of shot peening in conjunction with electric bonding has been covered. An analysis has been made to show the principal reasons for the observed reductions in fatigue strength and the way in which these are related to the size of the tested section.

For cases in which a selection of surface preparation methods is available, the grit blast process is preferred for all applications where the bond strength is adequate. The electric bond method is the least desirable from the standpoint of stress concentration, but is preferred over grooving or threading on small parts due to the smaller undercut required. The rough threading procedure is less damaging than grooving and knurling for parts subjected to flexural stresses, although both exert about the same effects in torsion.

Metallizing is used frequently for the repair of worn machinery components and the rebuilding of parts which have been mismachined in manufacture. Its use was stimulated greatly during the war, and much of the increase remains as a matter of peacetime economy. The variety of applications for metallizing are evident from a review of the technical press, and references (**1**) through (**8**)[3] are only a few which cover this subject.

It is unfortunate, however, that the metallizing process and its attendant methods of surface preparation usually result in a serious reduction of the fatigue resistance of a metallized part. This fact was apparent from the many failures experienced at the Engineering Experiment Station on the experimental reclamation of worn Diesel engine components. A review of the literature revealed practically no information regarding the endurance properties to be expected. Consequently, before attempting further application of the metallizing process to highly stressed machinery components, an investigation was initiated to determine how severe such fatigue damage could be and to select the best reclamation procedures for further service testing.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] The views expressed in this paper are those of the author and do not represent necessarily the opinions of the Navy Department.

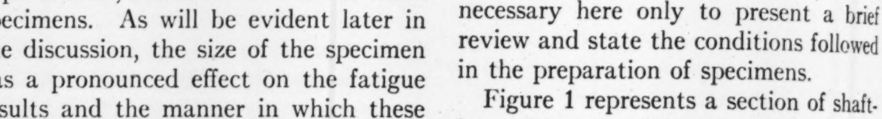
[2] Assistant Superintendent, Metallurgical Laboratory, U. S. Naval Engineering Experiment Station, Annapolis, Md.

[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 699.

SCOPE OF THE WORK

The data which are to be presented have been obtained with one general type of steel, tested in the form of small specimens. As will be evident later in the discussion, the size of the specimen has a pronounced effect on the fatigue results and the manner in which these results are interpreted. An attempt has been made, therefore, to treat the problem theoretically in order to relate, at least qualitatively, the results obtained on small sections to those which might be anticipated for larger parts.

The theoretical treatment has many debatable points. Nevertheless, the analysis is believed to be sufficiently accurate to demonstrate the trends which might be expected and, in that way, serve a useful purpose for those who are attempting to utilize the metallizing process as a means of reconditioning machinery parts.



$R_1 - R_2 = 0.030"$

$R_1 - R_3 = 0.055"$

FIG. 1.—Sketch Showing Dimensional Changes Occurring from the Four Conventional Methods of Preparing Specimens for Metallizing.

Recently the laboratory obtained facilities for the fatigue testing of specimens up to 2.5 in. in diameter. This has enabled experimental studies to be made on size effects and provides a means for verification of the theoretical treatment. It is hoped that the results of this work will be published when completed.

METALLIZING PROCEDURES

The various procedures for metallizing have been covered fully in the literature, and references (**9**) through (**15**) will serve as excellent sources of information for those who wish complete details. It is necessary here only to present a brief review and state the conditions followed in the preparation of specimens.

Figure 1 represents a section of shafting with an original radius R_1. For ordinary repair work the thickness of the metallized layer averages about 0.030 in. This is usually adequate to "true-up" worn parts and provides a sprayed layer heavy enough to withstand most service stresses. Consequently, the first step in reconditioning consists of undercutting the part 0.060 in. on the diameter.

The second step consists in preparing the surface to receive the sprayed metal. The bond is entirely mechanical, so that the surface preparation consists of a suitable roughening treatment. Selection of one of the various methods will depend principally on the machinability of the base metal, whether or not the part can be turned in a lathe, the strength of the bond required, and the location of the worn areas. When more than one method can be employed, the best is selected on a basis of resulting fatigue properties.

There are four common types of surface roughening treatments. These can be described briefly, according to the procedures followed in the preparation of specimens, as follows:

(*a*) *Electric Bonding* is essentially a low power welding operation in which the surface is roughened by a spattered deposit from nickel electrodes. The maximum height of the deposit depends on the voltage used, which in turn is selected as a function of the thickness of the sprayed metal to be applied. For the present tests, a medium voltage was employed, producing a peak height of about 0.020 in. A typical electric bonded and sprayed surface is shown in Fig. 2. The operation produces some local heating in the base material. Whereas the heat affected zone is extremely thin, it is known that such superficial surface conditions can affect the endurance properties. Furthermore, the surface is rough and can be expected to contain stress concentrating notches.

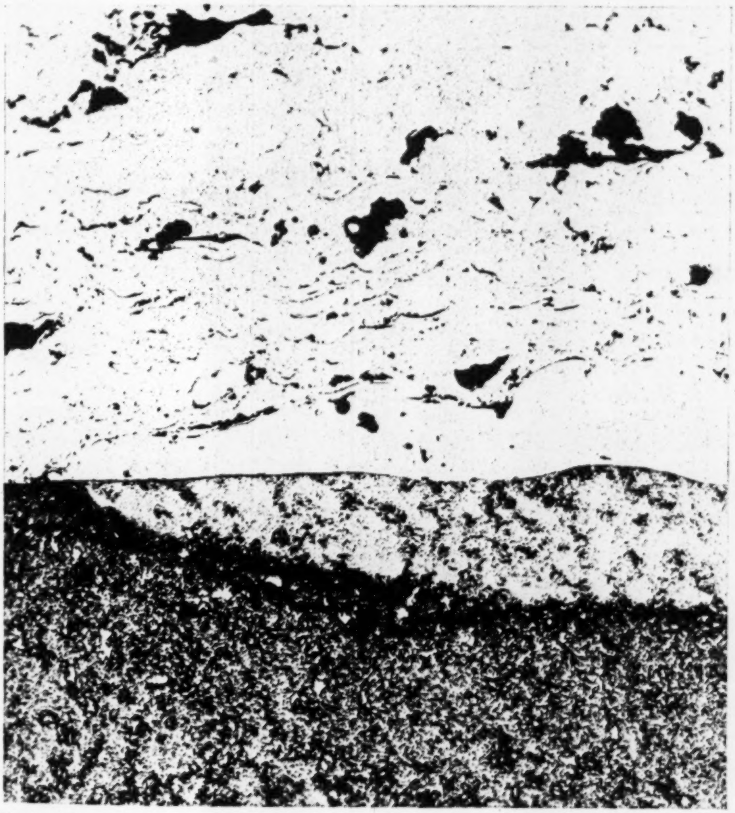


FIG. 2.—Photomicrograph Showing the Bond of a Typical Electric Bonded and Metallized Steel Shaft (×100). Etched in Nital.

(*b*) *Grit Blasting*, as employed in the preparation of specimens, roughens the surface by blasting with 20 to 40 mesh angular grit blown with 100 psi. air pressure. For the materials tested herein, a five minute blast per specimen was sufficient with a work-to-nozzle distance of 2 in. This type of surface preparation results in the weakest bond; however, if the bond is sufficient, the effects of the small sharp notches are partially nullified by the beneficial peening action obtained, at least when the underlying metal is relatively soft.

(*c*) *Rough Threading*, which is adaptable only to cylindrical work, is done with a 60 deg. pointed tool set to tear and burr the threads as they are cut. In making specimens, 16 threads per inch were cut to a depth of 0.025 in.

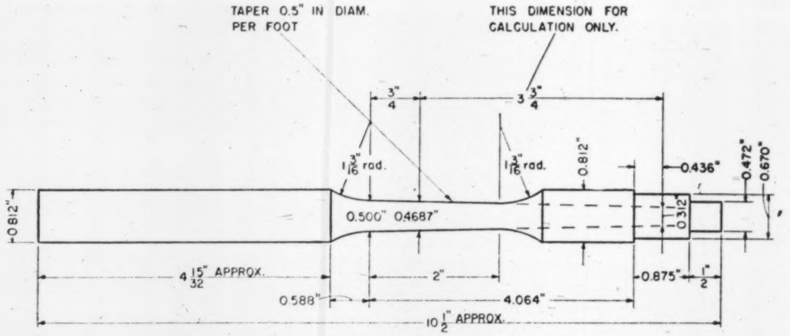

TAPER 0.5" IN DIAM. PER FOOT
THIS DIMENSION FOR CALCULATION ONLY.
3/4"
3 3/4"
1 3/16" rad.
1 3/16" rad.
0.812"
0.436"
0.472"
0.670"
0.812"
0.500" 0.4687"
0.312"
0.111
4 15/32" APPROX.
2"
0.875"
1/2"
0.588"
4.064"
10 1/2" APPROX.

FIG. 3.—Dimensions of Basic Rotating Cantilever (flexural) Endurance Specimen Before Surface Roughening and Metallizing.

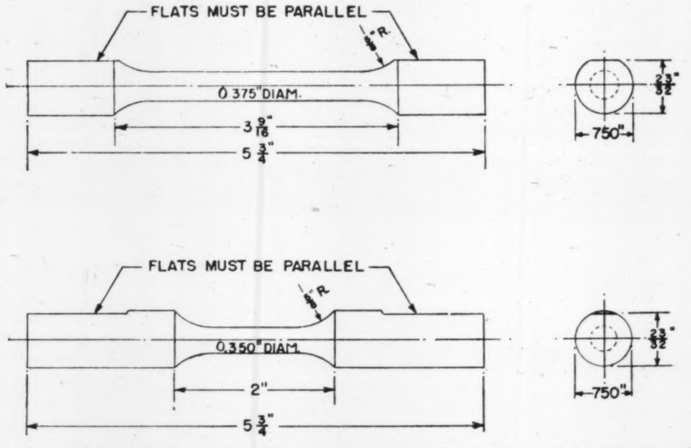

FLATS MUST BE PARALLEL
3/8" R.
0.375" DIAM.
3 9/16"
5 3/4"
23/32"
.750"
FLATS MUST BE PARALLEL
3/8" R
0.350" DIAM.
2"
5 3/4"
23/32"
.750"

FIG. 4.—Dimensions of Basic Alternating Torsion Endurance Specimens Before Surface Roughening and Metallizing.

(*d*) *Grooving and Knurling* requires special tools and also is adaptable only to cylindrical work. The grooves are cut as circumferential rings to a depth of 0.025 in. It is possible to make a spiral groove similar to a thread; however, multiple cutting tools usually are employed, thereby necessitating a circumferential notch. After the grooves are cut, the lands between the grooves are spread with a special knurling tool to produce a dovetail effect. In the preparation of specimens, the grooves were cut 16 to the inch with a land width of 0.015 in. before knurling.

The actual metallizing was accomplished with a wire-fed spray gun. Considerable latitude probably could be allowed in the operation of the gun, because it has been found by experience that the major effects on fatigue strength are caused by the methods of surface preparation, and very little strength can be regained by the application of the metallized layer. Nevertheless, the laboratory has standardized its spraying technique along accepted lines. All of the specimens to be discussed herein were sprayed as follows:

Wire	⅛ in. steel, 0.4 per cent carbon
Acetylene..............	15 psi.
Oxygen.................	15 psi.
Air....................	65 psi.
Work-to-nozzle	6 in.
Wire feed..............	2 ft. per min.
Method	Multipass
Lathe rotation.........	70 rpm.

METHODS OF TEST

The endurance tests were made both in flexure (rotating cantilever) and in alternating torsion. The basic specimens are shown in Figs. 3 and 4. The rotating cantilever specimen (Fig. 3) has a conically tapered gage length and is so designed that the maximum stress is 0.75 in. out from the inner fillet. The dimension at this point is used as a basis for stress calculation; however, the stress varies only about 1.5 per cent over a length of 1.5 in.

Two types of alternating torsion specimens were employed. (See Fig. 4). The 0.375-in. specimen is standard in the laboratory. In some cases, however, it was necessary to use the 0.350-in. specimen with the shorter gage length in order to obtain the desired level of stress.

All fatigue tests were made at 1450 stress cycles per minute. The mean stress in each case was zero.

The method of stress calculation plays an important part in the proper interpretation of the data. For these tests, the specimens shown in Figs. 3 and 4 were considered to represent members which originally were 0.060 in. larger in diameter and which had been undercut by that amount prior to metallizing. Since a reconditioned part is expected to carry the same service stresses as its original counterpart, the stresses were calculated on diameters 0.060 in. over those shown by the drawings.

Electric bonding and grit blasting produced no further significant changes of dimension after the undercutting operation. On the other hand, the rough threading and grooving and knurling operations reduced the diameter an additional 0.050 in. for a total reduction of 0.110 in.

Specimens prepared as described were tested both with and without the application of the metallized deposit. Those containing the metallized layer were finish machined to size and given one longitudinal polishing operation.

TABLE I.—BASE MATERIALS USED IN THE PREPARATION OF SPECIMENS.

Material Designation....	AFS	AFT
	Normalized at 1600 F. Tempered at 1200 F.	Normalized at 1600 F. Tempered at 1200 F.
Carbon, per cent..........	0.21	0.26
Manganese, per cent......	0.51	0.52
Silicon, per cent..........	0.23	0.23
Chromium, per cent.......	0.03	0.02
Nickel, per cent...........	2.84	2.99
Molybdenum, per cent....	0.05	0.02
Vanadium, per cent.......	0.15	0.14
Tensile strength, psi......	105 300	106 000
Yield strength, 0.1 per cent offset psi................	73 100	82 000
Elongation in 2 in., per cent....................	24	24.5
Reduction of area, per cent.	58	58
Brinell hardness...........	223	215

In determining the endurance limits of the fully polished base materials, specimens as shown in Figs. 3 and 4 were used. The endurance limits were assumed to be identical to those which would have been obtained with specimens larger by 0.060 in.

MATERIALS

The materials considered in this paper have been limited to normalized and tempered nickel-vanadium steel. Results on harder materials are not yet ready for publication. The steels which are included had the compositions and properties shown in Table I.

RESULTS OF TESTS

Rotating cantilever fatigue test results for material AFS are presented graphically in Fig. 5. A similar set of curves, for material AFT in alternating torsion, is shown in Fig. 6. In explanation of the graphs, the presence of a zig-zag line indicates the course of a test in which the stress was raised at intervals; the lower end of the line starts where the first stress increase was made. It is well to repeat that the stresses shown on the curves have been calculated with diameters 0.060 in. larger than those shown in Figs. 3 and 4.

A summary of the endurance limits is given in Table II, together with the total strength reduction factor obtained in each case. It may be noted that the term "strength reduction factor" is used in preference to "stress concentration factor." The latter term is related to the specimen size and the shape and location of the notch. The "strength reduction factor" is, in addition, related to the notch sensitivity of the steel, and is, therefore, the factor expressing the extent of the lowering of the endurance limit by introducing conditions of stress concentration, plus, in the case of the

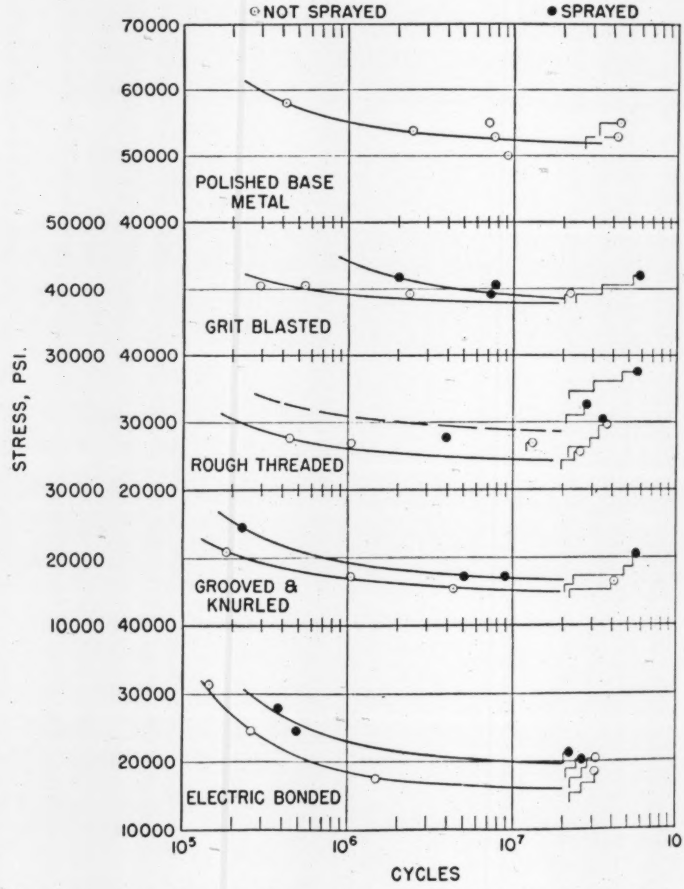


FIG. 5.—Rotating Cantilever (Flexural) Stress - Cycle Curves Obtained with Nickel-Vanadium Steel, Material AFS, Roughened by Four Methods of Surface Preparation, With and Without a Metallized Layer of 0.4 per cent Carbon Steel.

present tests, the effects of undercutting.

The total strength reduction factor is a useful number in predicting the behavior of the normalized and tempered nickel-vanadium steels in sections commensurate with the specimen sizes (size effects will be discussed later). However, a better understanding of the existing conditions is obtained if the two causes for the factor are isolated. That part which is attributable to the 0.060-in. undercut can be calculated precisely, because under a constant load the stress becomes a function of the cubes of the diameters. These factors due to the undercutting alone are indicated in the extreme right column of Table II.

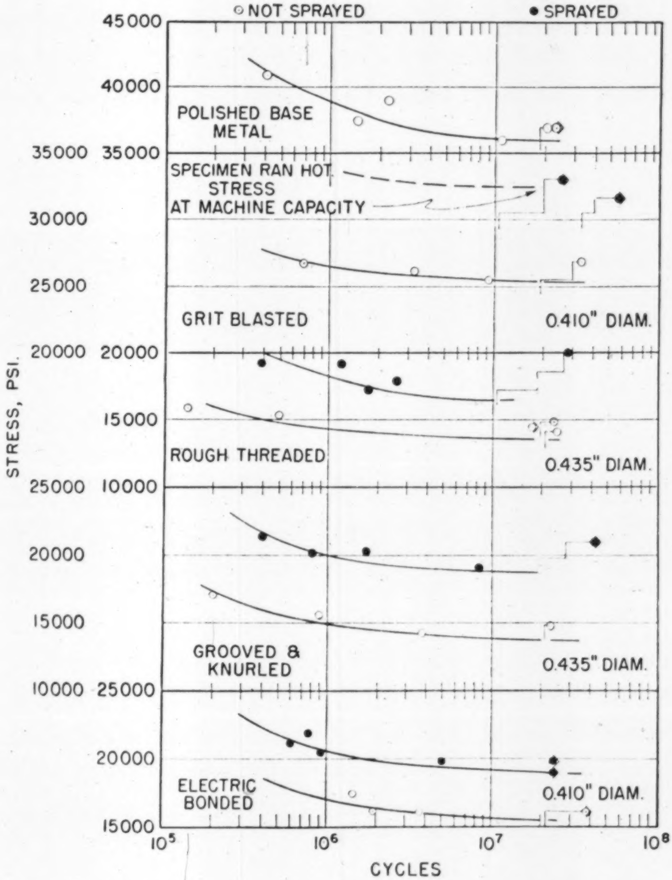


FIG. 6.—Alternating Torsion Stress-Cycle Curves Obtained with Nickel-Vanadium Steel, Material AFT, Roughened by Four Methods of Surface Preparation, With and Without a Metallized Layer of 0.4 per cent Carbon Steel.

A comparison in each case between the two factors listed in the table gives an excellent picture of the comparable damage caused by the various methods of surface preparation. It is of interest to note that the total reduction factors for the grit-blasted specimens are smaller than the reduction factors caused by undercutting alone. It is clear, therefore, that the grit blasting technique, despite the use of angular abrasives, has resulted in a beneficial peening effect.

The opposite is true for all the other methods of surface preparation.

The flexural fatigue tests have demonstrated the groove and knurl process to be far more damaging than the rough thread process, despite the much sharper notches in the latter. Similar observations were made by Moore (18) in his study of the effects of grooves and threads on the fatigue of metals. Moore has shown that circumferential grooves cause greater fatigue damage than continuous helical grooves of the same contour. A part of this can be accounted for by the fact that a given cross-section of a continuously threaded part is larger than the cross-section of a member with circumferential grooves. However, this does not explain all of the difference observed in the experiments, and other explanations are involved which at present are unknown. In the case of the alternating torsion tests, the rough-thread and the groove-and-knurl processes were essentially the same with respect to effects on the fatigue properties.

TABLE II.—SUMMARY OF FATIGUE TEST RESULTS ON NICKEL-VANADIUM STEEL SPECIMENS SURFACE ROUGHENED BY FOUR DIFFERENT METHODS, WITH AND WITHOUT A METALLIZED LAYER OF 0.4 PER CENT CARBON STEEL.

Type of Test	Material Designation	Surface Condition of Test Specimens	Diameter Used for Stress Calculation, in.	Actual Over-all Diameter of Specimen as Tested, in.	Endurance Limit, psi.	Total Strength Reduction Factor	Strength Reduction Factor Due Only to Undercutting 0.060 in.
Flexure (Rotating Cantilever)	**AFS**	Polished	0.528	0.468	52 000	1.00[a]	—
		Grit blasted	0.528	0.468	37 500	1.39	1.44
		Grit blasted, sprayed	0.528	0.528	38 500	1.35	1.44
		Rough threaded	0.528	0.468	24 500	2.12	1.44
		Rough threaded, sprayed	0.528	0.528	28 500?	1.82	1.44
		Grooved, knurled	0.528	0.468	15 000	3.46	1.44
		Grooved, knurled, sprayed	0.528	0.528	16 500	3.15	1.44
		Electric bonded	0.528	0.468	16 000	3.24	1.44
		Electric bonded, sprayed	0.528	0.528	19 500	2.66	1.44
Alternating Torsion	**AFT**	Polished	0.435	0.375	36 000	1.00[a]	—
		Grit blasted	0.410	0.350	25 500	1.41	1.61
		Grit blasted, sprayed	0.410	0.410	32 500	1.14	1.61
		Rough threaded	0.435	0.375	13 500	2.66	1.56
		Rough threaded, sprayed	0.435	0.435	16 500	2.18	1.56
		Grooved, knurled	0.435	0.375	13 500	2.66	1.56
		Grooved, knurled, sprayed	0.435	0.435	18 500	1.94	1.56
		Electric bonded	0.410	0.350	15 500	2.32	1.61
		Electric bonded, sprayed	0.410	0.410	19 000	1.90	1.61

[a] Endurance limit of polished base metal assumed to have no size effect within the range of sizes investigated.

The results shown in Table II and Figs. 5 and 6 indicate that very little strength is gained by the application of the metallized layer. In other words, the damage is done by the surface preparation, and this is by no means nullified by the sprayed coating. Of course, some slight gain of strength can be noted, and it is of interest to observe that the sprayed metal is more able to carry a share of the load when the specimen surface is prepared by a drastic roughening treatment. Apparently, then, this is partially related to the strength of the bond. In larger sections, the sprayed layer would have even less significance in so far as increasing the strength of the part is concerned.

It is perhaps unfortunate that the electric bonding method of surface preparation results in such deleterious effects on the fatigue properties. This surface roughening process produces a strong bond and has the advantage of being applicable to all shapes and hardness of parts to be reconditioned. For this reason a few tests were made to determine whether shot peening could be used in any way to overcome the deleterious effects.

Electric bonded rotating cantilever

specimens, of material AFT, were prepared as before with the addition of shot peening at various stages of preparation. The peening was performed with a special motor-driven jig which rotated the specimens in the blast stream at 3 rpm. Control of the peening intensity was obtained by mounting type A Almen specimens on a fixture and subjecting them to the same peening conditions. The operating conditions of the blasting equipment consisted of 120 psi. air pressure, 3 in. nozzle-to-work distance, 1 in. per second longitudinal nozzle travel and S.A.E. No. 550 size chilled iron shot. A blasting time of 7 min. per specimen was equivalent to 0.015 in. deflection of a type A peening intensity specimen on an Almen gage No. 1 (19).

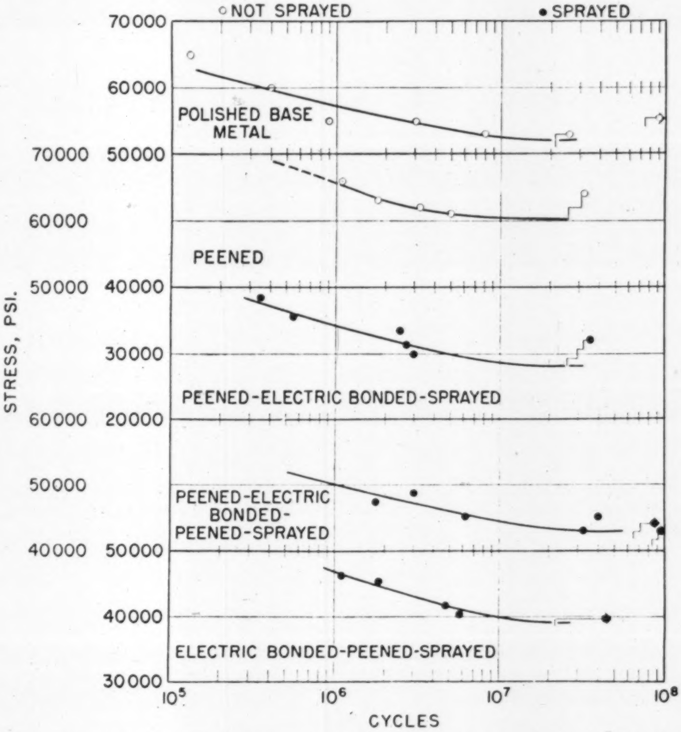


FIG. 7.—Rotating Cantilever (Flexural) Stress-Cycle Curves Obtained with Nickel-Vanadium Steel, Material AFT, Showing the Effects of Shot Peening at Various Stages in the Electric Bonding and Metallizing Process.

The results of the fatigue tests are presented in Fig. 7 and Table III. These values show an expected improvement to be obtained by shot peening of the electric bonded surface. A slight additional improvement is noted if the base material also is peened prior to electric bonding. Subsequent shear tests showed a reduction of 25 per cent in bond strength to result from the peening of the electric bonded surface.

COMPARISON OF RESULTS WITH THOSE IN THE LITERATURE

Practically no information exists in the technical literature regarding the endurance properties of metallized specimens. Ballard (20) has given consideration to this subject, although his statements have been based on service observations rather than on controlled experiment. He believes that the effects of surface blemishes have been exaggerated, because he has not heard of a single service failure of a metallized part. These observations do not agree with this laboratory's experiences, either with fatigue specimens or in actual service tests of sprayed parts in Diesel engines.

A paper by Horger and Buckwalter (21) regarding metal-coated and flame-hardened axles contains some limited information. These authors concluded that "plain specimens 2 in. in diameter of annealed S.A.E. 1035 steel showed little change in endurance limit with and without the metal-coated layer." However, their specimens had been prepared for spraying only by sandblasting, in which case their results are not surprising. On the other hand, Fuller, in discussing the paper by Horger and Buckwalter, presented evidence which showed a decided lowering of fatigue strength. His tests were made on S.A.E. 1035 steel, apparently using the same rotating cantilever specimen as shown in Fig. 3. Fuller's results are summarized in Table IV, in which the strength reduction factors were calculated by the author. Full details of the processes were not given, although the sprayed layer thickness was one-eighth of the specimen diameter. The tests of Fuller, whereas not directly comparable, do not contradict the present experiments.

TABLE III.—SUMMARY OF FATIGUE TEST RESULTS ON NICKEL-VANADIUM STEEL, MATERIAL AFT, SHOWING THE EFFECTS OF SHOT PEENING AT VARIOUS STAGES IN THE PREPARATION OF ELECTRIC BONDED AND METALLIZED SPECIMENS.

Surface Condition of Test Specimens	Diameter Used for Stress Calculations, in.	Actual Over-all Diameter as Tested, in.	Endurance Limit, psi.	Total Strength Reduction Factor
Fully polished base metal	0.528	0.468	52 000^{a}	1.0
Base metal peened only	0.528	0.468	60 000^{a}	0.87
Peened, electric bonded, sprayed	0.528	0.528	28 000	1.9
Peened, electric bonded, peened, sprayed	0.528	0.528	43 000	1.2
Electric bonded, peened, sprayed	0.528	0.528	39 000	1.3

^{a} Assumed to have no size effect within the range of sizes investigated.

TABLE IV.—FATIGUE TESTS OF METALLIZED SPECIMENS AS REPORTED BY FULLER (21).

Specimen	Endurance Limit, psi.	Strength Reduction Factor
Base metal	39 000	1.0
Shot blasted and sprayed	34 000	1.15
Rough machined (0.003 in. deep threads) and sprayed	31 500	1.25
V notch 0.035 in. deep, 67 deg. flank, 0.001 in. radius	19 000	2.05

CONSIDERATION ON SIZE EFFECT

The methods used to report the results in Tables II and III are more or less sufficient for the comparison of fatigue properties on commensurate sizes of shafts. However, they do not satisfy requirements for applying the results to larger or smaller parts. The reason for this, as demonstrated by Neuber (22) and others, is that the stress concentration factor for any particular notch is a function of the diameter of the shaft and the depth of the notch. For any size of shaft and notch radius, there is an optimum notch depth resulting in maximum stress concentration; notches shallower or deeper than the optimum value produce smaller concentration factors.

At the time these fatigue tests were made, no facilities were available for the experimental determination of the effects of size on the metallized specimens. Consequently, a theoretical analysis was made to determine such effects, at least on a qualitative basis. Whereas actual experiments are now under way with large specimens, it is believed that the theoretical approach offers sufficient interest to be presented.

The recent work of Neuber (22) is perhaps the best source of information pertaining to notches and stress concentration factors as they might apply here. The chief advantage to the work rests in the fact that stress concentration can be calculated for notches of any radius of curvature and of any depth occurring in any size of shaft. It is emphasized that the validity of the Neuber theory has not been completely confirmed, although the theory certainly is suitable for indicating the trends to be expected.

TABLE V.—TECHNICAL STRESS CONCENTRATION FACTORS FOR TWO NOTCHES IN SOLID CIRCULAR SHAFTS UNDER BENDING STRESSES, CALCULATED BY NEUBER'S EQUATIONS.

Shaft Diameter at Smallest Cross-Section, in.	Depth of Notch, in.	Radius of Curvature of Notch, in.	Flank Angle of Notch, deg.	Technical Stress Concentration Factor *K*
0	0.025	0.025	0	1.00
0.20				1.41
0.50				1.67
1.0				1.84
2.0				1.94
4.0				1.99
6.0				2.03
infinite				2.07
0	0.025	0.001	60	1.00
0.10				1.54
0.20				1.73
0.50				1.98
1.0				2.12
2.0				2.22
4.0				2.27
6.0				2.29
infinite				2.33

Two series of calculations have been made for notches in solid circular shafts under bending stresses. The technical stress concentration factors were calculated using the Neuber equations shown in the Appendix. Results of the calculations are given in Table V.

It is pointed out that the dimensions of the first notch are similar to that produced by the grooving operation. The second notch, with a flank angle of 60 deg. and a radius of curvature of 0.001 in., approximates the condition introduced by a rough threading operation, with the exception that the calcula-

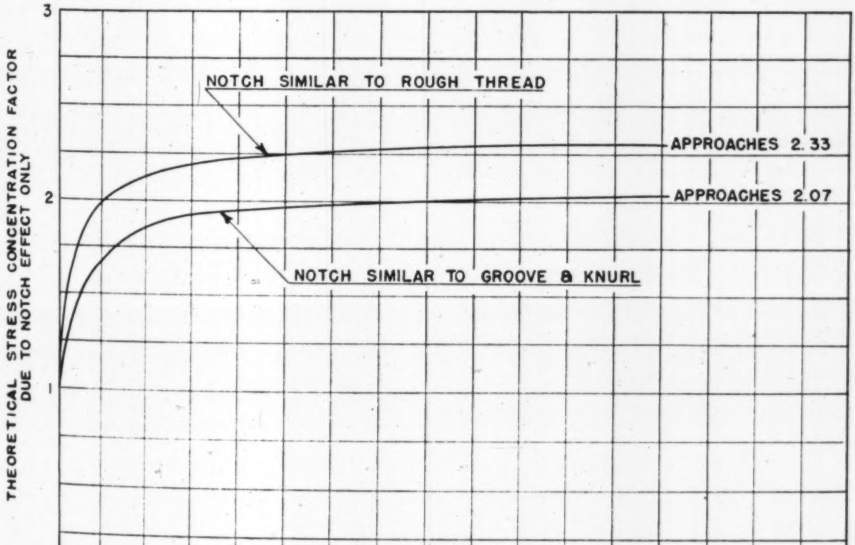


FIG. 8.—Technical Stress Concentration Factors for Two Notches as a Function of the Diameter of a Solid Circular Shaft Under Bending Stresses. Calculations Made According to Neuber's Equations in Appendix.

tions as shown do not take into account the spiral form of the notch actually obtained in preparing a shaft for metallizing. Both notches are 0.025 in. in depth, a figure consistent with actual practice.

Graphical presentation of the data in Table V is given in Fig. 8. After a shaft reaches 1 to 2 in. in diameter and above, the stress concentration factor is fairly constant as the shaft size varies.

threading or grooving and knurling, therefore, Neuber's calculations would be based on radii R_2 and R_3.

Naturally it would be best if the stress calculations could be related to the original radius, R_1, of a reconditioned shaft. This can be done by (1) calculating the increase in stress due to the undercutting plus, in the case of threading or grooving, the increase due to the additional 0.025 in. depth of the notch, and (2) multiplying the value so obtained by the calculated stress concentration factor introduced by the notch. For example, consider a shaft 1.110 in. in diameter. When it is undercut and grooved and knurled, the smallest diameter then becomes 1.000 in. The nominal stress increases as a function of the cube of the diameter. Hence, in carrying the same load, the stress would increase 1.37 times before any consideration is given to the

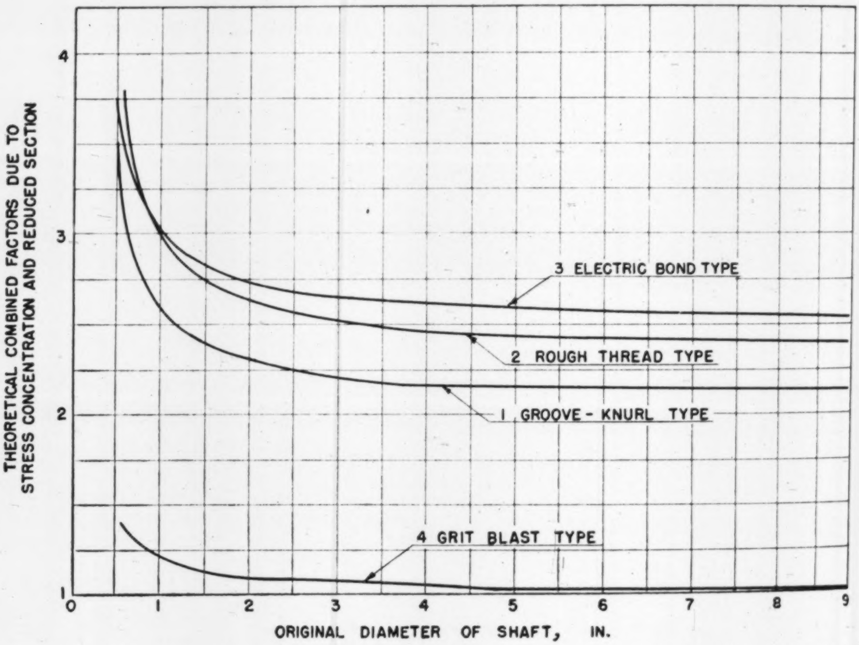


FIG. 9.—Theoretical Combined Factor Due to Stress Concentration and Reduced Section, in a Solid Circular Shaft Under Bending Stresses, Resulting from Four Methods of Surface Preparation Prior to Metallizing.

It is well to point out that in the presentation of the experimentally determined strength reduction factors in Table II, stresses were calculated using the original radius and the radius after a 0.030 in. undercut, corresponding to R_1 and R_2, respectively, in Fig. 1. Neuber's equations, on the other hand, are based on the smallest radius occurring at the base of the notch. (See Fig. 11 in the Appendix.) In the case of rough notch effect. Next, according to Neuber's theory, the stress concentration factor introduced by the notch effect is 1.84. Finally, the total effect resulting from the reconditioning of a 1.110 in. shaft is a stress increase of 2.52 (1.84 times 1.37).

As pointed out previously, the application of the sprayed metal, to return the part to its original size, does not add very much strength to the shaft over that in the undercut and notched condition. By making the results somewhat conservative, the slight beneficial effects of the sprayed metal can be ignored for the present in the calculation of stresses.

TABLE VI.—TYPICAL CALCULATIONS FOR SHOWING DERIVATION OF COMBINED FACTOR DUE TO STRESS CONCENTRATION AND REDUCED SECTION IN AN UNDERCUT AND ROUGH THREADED SHAFT.

Original Diameter of Part, in.	Diameter After Undercutting and Rough Threading, in.	Factor of Stress Increase Due to Reduction in Cross-Section	Stress Concentration Factor Due to the Notch, K	Combined Factor Due to Stress Concentration and Reduced Section
0.110	.00	infinite	1.00	infinite
0.210	.10	9.3	1.54	14.3
0.310	.20	3.73	1.73	6.45
0.610	.50	1.81	1.98	3.58
1.110	1.00	1.37	2.12	2.90
2.110	2.00	1.18	2.22	2.62
4.110	4.00	1.08	2.27	2.45
6.110	6.00	1.055	2.29	2.42
infinite	infinite	1.00	2.33	2.33

The entire stress increase calculated in the above manner has been called the *combined factor due to stress concentration and reduced section*. Curves 1 and 2 in Fig. 9 show such combined factors, as a function of the original shaft size, for the groove and knurl and rough thread types of surface preparation. Typical calculations, as used for the rough thread curve, are given in Table VI.

In the case of electric-bonded or grit-blasted shafts, the situation is not adapted to such precise treatment. Nothing is known regarding the dimensions and orientations of the notches, and hence it is not possible to make calculations with the Neuber equations. Nevertheless, it is apparent that grit blasting and electric bonding produce effects which are equivalent to measurable notches.

If the equations in the Appendix are examined, it is noted that in dealing with very shallow sharp notches (where the notch depth is less than that producing maximum stress concentration in a shaft of any particular diameter), the stress concentration factor decreases as the notch depth decreases, reaching a limit of 1.00 when the notch depth is zero. It is noted further that the stress concentration for such notches is not expected to vary significantly over a practical range of shaft sizes. Therefore, if it were possible to construct curves of notch stress concentration factors for electric-bonded and grit-blasted shafts, similar to the curves shown in Fig. 8, the critical portions of the curves would occur to the left of 0.5-in. diameter, the remainder of the curves being nearly horizontal. Consequently, we may assume for practical purposes that the technical notch stress concentration factor produced by grit blasting or electric bonding is constant for various sizes of shafts above 0.5 in. in diameter.

TABLE VII.—STRENGTH REDUCTION FACTORS OBTAINED FROM ROTATING CANTILEVER TESTS OF MATERIAL AFS. ORIGINAL SIZE OF SHAFT 0.528-IN. DIAMETER.

Method of Surface Preparation	Smallest Diameter After Preparation, in.	Strength Reduction Factor		
		Due to Reduction in Diameter	Due to Notch Effect	Combined Factor
Polished	0.528	1.00	1.00	1.00
Electric-bond	0.468	1.44	2.25	3.24
Groove-knurl	0.418	2.02	1.71	3.46
Rough-thread	0.418	2.02	1.05	2.12
Grit-blast	0.468	1.44	0.96	1.39

Now ductile materials are not completely notch sensitive, that is, the endurance limit may not be lowered to the full extent indicated by the stress concentration factor. Consequently, it is not possible to determine from the endurance tests the actual amount of stress concentration caused by electric bonding. It is assumed, though, that a curve for electric bonding, if it were drawn in Fig. 8 between 0.5 and 8-in. diameters, would be a horizontal line at some unknown ordinate value. It is possible to assign an arbitrary value of stress concentration which will satisfactorily meet the needs of this discussion. As will be shown later in Table VII, the electric bonding method of surface preparation is the most damaging of all the methods tested, in so far as stress concentration due to notches is concerned. The tests of material AFS show a strength reduction factor of 2.25 caused by the notch alone, as will be seen subsequently. Then, if the material is not completely notch sensitive, it is safe to assume that the actual stress concentration factor is at least 2.5.

Based on this factor of 2.5, and making corrections for undercutting the original shaft diameter, curve No. 3 has been drawn in Fig. 9 to represent the trend taken by electric-bonded shafts. As would be expected, the trend indicates that for very small shafts the electric-bond method would become superior to the grooving and knurling or rough threading treatments, because the latter two methods require 0.110 in. to be removed from the original diameter as compared with 0.060 in. for electric bonding.

The grit blast method of surface preparation improved the endurance properties of the steels tested. The beneficial peening effect was obtained with sharp abrasives and might not result in improvement for all materials. Hence, it is probably safe to assume that the stress concentration factor due to notches introduced by grit blasting of soft steels would be about 1.0, that is, no stress concentration. In this case, the strength reduction would result only from undercutting of the shaft. Curve No. 4 in Fig. 9 represents the trend so obtained for the grit blast method.

The previous few paragraphs have described the derivations of the theoretical curves in Fig. 9. These curves are important because they show the expected trends relating the combined factors due to stress concentration and reduced section, for various methods of surface preparation, to a range of shaft sizes. These curves are not presented for the purpose of giving exact factors; in fact, the values may well be in considerable error. This, however, is no great handicap to the present purpose, because the fatigue strength of a ductile material is not reduced to the full extent indicated by a stress concentration factor. Hence, regardless of the state of knowledge of the stress concentration, it is necessary to make fatigue tests to determine the behavior of a notched material under cyclic stresses.

Table VII presents the strength reduction factors obtained from the Station's rotating cantilever tests on material AFS as calculated according to the methods used in obtaining Fig. 9. Each combined strength reduction factor is shown broken down into its two components, namely, the factor due to the reduction in shaft section and the factor due to the notch. The combined factor, of course, corresponds to the total strength reduction factor listed in Table II.

These results can be considered in connection with the curves in Fig. 9. As indicated in the table, the grit blast method is by far the least damaging to the endurance properties, and therefore curve No. 4 is shown in its proper relative position. The grit blast method of surface preparation is to be highly preferred over all other methods, provided that the bond strength is adequate.

The experimental results show that

the groove-and-knurl process is more damaging than the rough continuous thread, although the latter has a sharper notch and both notches are cut to the same depth. Mention has already been made of similar observations of Moore (18) in his studies on the fatigue of threaded sections. Hence, the relative positions of curves No. 1 and No. 2 are reversed in actual practice. This effect was found only in the flexure tests, and, as will be shown, serious damage by rough threading is evident in torsion.

Electric bonding introduces more damaging notch effects than any of the other methods of surface preparation. One advantage of electric bonding is that the shaft diameter is not undercut as much as in the cases of threading or grooving. Hence, for very small shafts, the smaller strength reduction factor due to undercutting may counterbalance the more severe notch concentration factor. This is indicated in Fig. 9 by the crossing of curves No. 2 and No. 3 at a shaft size somewhat below 1 in., and undoubtedly explains why the combined strength reduction factor for electric bonding was less than that for the grooving in the fatigue tests on small specimens.

The results obtained in the alternating torsion tests can be treated with the same type of analysis. Figure 10 presents a set of theoretical curves for torsion which are analogous to those in Fig. 9 for bending. In this case it was assumed that the stress concentration factor from the notch alone was 1.8 for electric bonding and 1.0 for grit blasting over a range of shaft sizes from 0.5 to 8 in.

Table VIII lists the strength reduction factors obtained by experiment and calculated according to the method used to derive Fig. 10. (Table VIII is analogous to Table VII.) Again, the combined factors equal the total strength reduction factors listed in Table II.

These results in general conform to those found in the rotating cantilever tests. As would be expected from the above table, the greatest damage occurred to the small specimens by rough

TABLE VIII.—STRENGTH REDUCTION FACTORS OBTAINED FROM ALTERNATING TORSION TESTS OF MATERIAL AFT.

Method of Surface Preparation	Original Shaft Diameter, in	Smallest Diameter After Preparation, in.	Strength Reduction Factor		
			Due to Reduction in Diameter	Due to Notch Effect	Combined Factor
Polished	0.435	0.435	1.00	1.00	1.00
Electric-bond	0.410	0.350	1.61	1.44	2.32
Groove-knurl	0.435	0.325	2.40	1.11	2.66
Rough-thread	0.435	0.325	2.40	1.11	2.66
Grit-blast . . .	0.410	0.350	1.61	0.88	1.41

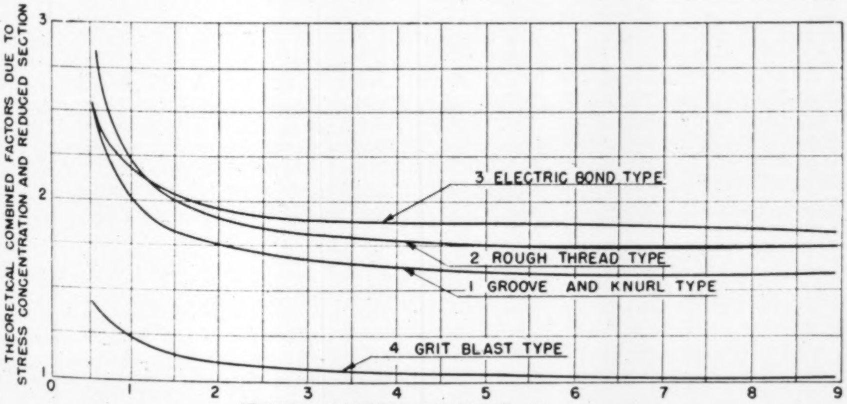


FIG. 10.—Theoretical Combined Factor Due to Stress Concentration and Reduced Section, in a Solid Circular Shaft Under Torsional Stresses, Resulting From Four Methods of Surface Preparation Prior to Metallizing.

threading or grooving and knurling, the reason being that these methods of surface preparation required greater reduction of the shaft diameter prior to metallizing. Consequently, for larger shafts, where the effects of undercutting are less pronounced, it is expected that the electric-bond method of surface preparation would produce the greatest combined strength reduction factor, since this method produces the greatest stress concentration as a notch. Such a trend is shown in Fig. 10 by the crossing of curves No. 1 and No. 2 by curve No. 3.

It is well to point out again the one notable difference between the rotating cantilever and alternating torsion results. In the case of the cantilever specimens, the continuous nature of the rough threads resulted in far less damage than the circumferential grooves. In the alternating torsion tests, the rough thread and groove and knurl processes were about equally effective in reducing fatigue strength.

Grit blasting with sharp angular grit once again produced a beneficial peening effect. However, the steels used in the tests were relatively soft and insensitive to notches, and harder steels might not be benefited by grit blasting.

CONCLUSIONS

The method to be selected for preparing surfaces for metallizing depends to a considerable extent on the nature, size and shape of the part being reconditioned. Nevertheless, in many cases, particularly for cylindrical parts, any one of a number of procedures can be chosen. In such cases, the grit-blast method of surface preparation is to be greatly preferred, provided the bond strength is adequate. In the case of quite soft materials, at least, the endurance properties will not be affected other than by loss in strength due to undercutting. Grit blasting prior to metal spraying is recommended for parts subjected to both bending and torsional stresses.

The experimental results indicate that electric bonding introduces more serious notch effects than either rough threading or grooving and knurling. However, the latter two processes require a greater amount of undercutting to be performed on a part being reconditioned. Consequently, in small parts, where the effects of undercutting are felt the most, the added loss in strength due to the extra undercutting can overshadow the notch effects. Judging from theoretical considerations, as well as the experimental results from small specimens, the electric-bond method would be better for parts under about 1 in. diameter, and either the rough threading or grooving and knurling process for shafts of larger sizes. This size effect occurs with both bending and torsional stresses. Electric bonding, of course, must be used on steel of any size if the steel is too hard to machine.

The test results with rotating cantilever specimens show that the groove-and-knurl process is more damaging than the continuous rough-thread, even though the latter has a sharper notch contour and both are cut to the same depth. A part of this is due to the smaller area in any cross-section through a circumferential groove. In addition, however, certain unknown features connected with continuous threads must account for the remainder of the superiority. Similar observations by other investigators have been noted in fatigue studies of threaded bolts. The superiority is pronounced only in the rotating cantilever test; in alternating torsion the rough threading and grooving and knurling processes are about equally damaging to the fatigue strength of steel.

These tests have been conducted on relatively soft machinery steels which are not expected to be very notch sensitive. Harder materials undoubtedly would be damaged to a greater extent from the notches introduced by the surface preparations.

Whereas the theoretical discussions contained in this report point the way toward interpretation of the data to larger sizes of specimens, it will be necessary to make tests on larger specimens before any degree of certainty is attained. Such experimental work is now in progress.

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APPENDIX

Calculations using Neuber's (22) theory are based on the following symbols and equations:

Let k_1 = stress concentration factor calculated as a deep notch.
k_2 = stress concentration factor calculated as a shallow notch.
K' = stress concentration factor of an ideal material (obeys classic theory of elasticity).
K = technical stress concentration factor.
μ = Poisson's ratio.
r = radius of notch curvature.
t = depth of notch.
a = radius of shaft at base of notch.
r' = elastic notch sensitivity (related to texture of material) and reported to equal 0.0189 in. for steel.
w = flank angle of notch.

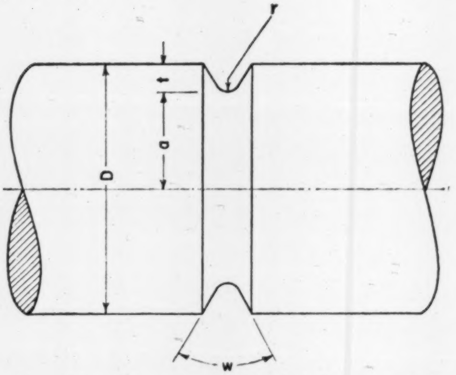

FIG. 11.—Dimensional Symbols Employed in the Execution of Neuber's Equations.

For bending stress on solid circular shafts:

$$k_1 = \frac{1}{N} \cdot \frac{3}{4}\left(\sqrt{\frac{a}{r}+1}+1\right) \cdot \left[3\frac{a}{r} - \left(1-\frac{2}{\mu}\right)\sqrt{\frac{a}{r}+1} + 4 + \frac{1}{\mu}\right]$$

$$\text{where } N = 3\left(\frac{3}{r}+1\right) + \left(1+\frac{4}{\mu}\right) \cdot \sqrt{\frac{a}{r}+1} + \frac{1+\frac{1}{\mu}}{1+\sqrt{\frac{a}{r}+1}}$$

$$k_2 = 1 + 2\sqrt{\frac{t}{r}}$$

$$K' = 1 + \frac{(k_1-1)(k_2-1)}{\sqrt{(k_1-1)^2+(k_2-1)^2}}$$

$$K = 1 + \frac{K'-1}{1+\frac{\pi}{\pi-w}\sqrt{\frac{r'}{r}}}$$

For torsional stress on solid circular shafts:

$$k_1 = \frac{3\left(1+\sqrt{\frac{a}{r}+1}\right)^2}{4\left(1+2\sqrt{\frac{a}{r}+1}\right)}$$

$$k_2 = 1 + \sqrt{\frac{t}{r}}$$

K' and K, same as for bending stresses.

DISCUSSION

MR. SAM TOUR.[1]—This is a very interesting paper and contains some very valuable and worth-while data. It is hoped that more work will be done along this line.

In the paper the statement is made that if the material is too hard to be grooved or knurled, then, the electric bonding method must be used.

This might be modified a bit in view of the development within the past year and a half of spray bonding for hard materials. Where hard materials cannot be grit blasted adequately for good bond and are too hard to be rough threaded or grooved and knurled, the spray bonding method applies. The spray bond wire is applied with a metallizing gun direct upon the hard surface and adheres as a thin layer upon which then the regular sprayed metal coating can be applied.

It is possible with the spray bonding method to get adherence equal to that obtained on grit blasting a soft steel (good adherence is obtainable even on case hardened or 60 "C" Rockwell hard) surfaces. It would be interesting if the author of this paper would extend his work to include spray bonded surfaces.

MR. W. L. WILLIAMS (*author's closure*).—Mr. Tour's remarks are appreciated greatly. As he has pointed out, the spray bond method is a rather new development. We had undertaken the testing of the method, but unfortunately the results were not ready at the time the paper was presented to the Society. However, at this time the tests are sufficiently well along to mention a few conclusions.

Spray bonding is an effective method of producing a metallized bond without the necessity of roughening the base metal. It is applied with the metallizing gun and requires only the set-up necessary for the ordinary metallizing process itself. This has obvious practical attractions to the metallizing shop. However, spray bonding lowers the fatigue resistance of the base metal, despite the elimination of the base metal roughening treatments associated with other bonding practices. The extent of the lowering of the fatigue resistance is about of the same magnitude as that resulting from electric bonding.

It may be of interest to know that our tests of larger specimens also are nearly completed for shaft diameters of 1.5 in. Almost without exception, the trends on size effect have been realized as indicated by the theoretical treatment in this paper.

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[1] President, Sam Tour and Co., Inc., New York, N. Y

A NEW HIGH-SPEED SHEET METAL FATIGUE TESTING MACHINE FOR UNSYMMETRICAL BENDING STUDIES*

By G. R. Gohn[1] and E. R. Morton[1]

Synopsis

This paper describes a constant deflection fatigue machine suitable for testing in bending 24 sheet metal specimens simultaneously at as many as 12 different values of mean stress and at any testing speed up to 3000 rpm. Alternating stresses ranging from zero to a maximum value corresponding to a deflection of 1 in. may be superimposed upon any mean stress of such magnitude that the total deflection does not exceed 2 in. The novel feature of the machine consists in driving the free end of the cantilever-beam specimens through an arc which corresponds to the normal path of the free end of the deflected beams. This is accomplished by passing the specimens through rock shafts carrying adjustable deflecting arms which bend the specimens, not about the point of clamping, but a point in space representing the center of the arc through which the free end of the specimens travel. The rock shafts are oscillated by means of a variable throw crankshaft, connecting rods and Pitman arms. Continuous lubrication is obtained from splash feed. An electronic monitoring system records the number of cycles to failure. The machine is capable of testing sheet or strip metal varying in thickness from 0.010 to 0.050 in.

Discussion of Fatigue Testing with Unsymmetrical Loading

Experience has shown that the physical tests which most nearly simulate service conditions yield data of greatest usefulness to the materials engineer and to the designer. The need for this type of testing is particularly great in the field of fatigue where, either because of the lack of suitable testing equipment or because of limitations in machine design, it has become the general practice to determine the fatigue characteristics of engineering materials, not on the basis of simulated service tests but on the basis of tests made on polished specimens—either notched or unnotched—under conditions of completely reversed stress. For applications in which the mean stress is not zero, modified Goodman diagrams have been constructed from a knowledge of the tensile strength and the fatigue characteristics of the material at zero mean stress, and these diagrams used to estimate the fatigue strength at other mean stresses.

The modified Goodman diagram has been expressed by the equation

$$S_a = S_n \left(1 - \frac{S_m}{S_u}\right) \quad \ldots \quad (1)^*$$

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] Members of Technical Staff, Bell Telephone Laboratories, Inc., New York, N. Y.

* The symbols used in this equation differ slightly from those used by Gohn and Ellis in their previous paper "The Fatigue Characteristics of Copper-Nickel-Zinc and Phosphor Bronze Strip in Bending Under Conditions of Unsymmetrical Loading," *Proceedings*, Am. Soc. Testing Mats., Vol. 47, p 713, (1947). These changes have been made to conform to the symbols used in the Manual on Fatigue Testing prepared by A.S.T.M. Committee E-9 on Fatigue.

where:

S_a = the alternating stress amplitude, that is one half of the safe range of stress, in pounds per square inch. (In this paper the term "safe range of stress" will be used without further qualification to mean the range of stress corresponding to 10^8 cycles of alternating stress),

S_n = the fatigue strength in pounds per square inch corresponding to an infinite number of cycles of completely reversed stress. (In this paper the term S_n is used to denote the fatigue strength of "as-rolled," cross-milled longitudinal specimens of strip material for 10^8 cycles of completely reversed stress),

S_m = the mean stress in pounds per square inch, that is the algebraic mean of the maximum and minimum stress in one cycle, and

S_u = the static ultimate tensile strength in pounds per square inch.

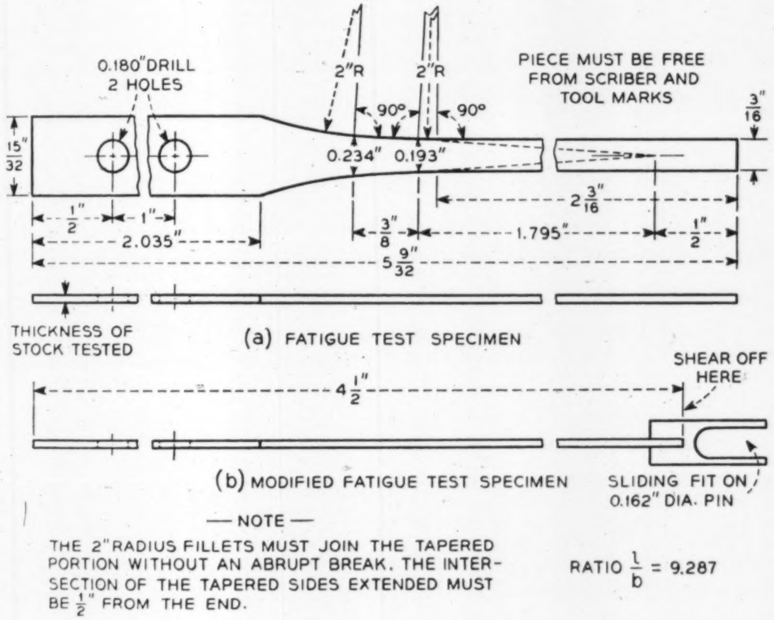
0.180" DRILL
2 HOLES
2"R
2"R
90°
90°
PIECE MUST BE FREE FROM SCRIBER AND TOOL MARKS
3/16"
15/32"
0.234"
0.193"
2 3/16"
1/2"
1"
2.035"
3/8"
1.795"
1/2"
5 9/32"
THICKNESS OF STOCK TESTED
(a) FATIGUE TEST SPECIMEN
SHEAR OFF HERE
4 1/2"
(b) MODIFIED FATIGUE TEST SPECIMEN
SLIDING FIT ON 0.162" DIA. PIN
— NOTE —
THE 2" RADIUS FILLETS MUST JOIN THE TAPERED PORTION WITHOUT AN ABRUPT BREAK. THE INTERSECTION OF THE TAPERED SIDES EXTENDED MUST BE 1/2" FROM THE END.
RATIO l/b = 9.287

FIG. 1.—Fatigue Test Specimen.

However, J. O. Smith (**1**)[2] has shown that Eq. 1 does not apply to ductile materials subjected to torsional fatigue nor to axially loaded, notch-free, ductile specimens in which the mean stress was compressive. Gohn and Ellis (**2**) have also shown that this equation fails to apply to at least two nonferrous sheet metals tested in bending. The latter authors further suggested the desirability of making additional studies on sheet metal to determine the relation between mean stress and alternating stress in bending under various conditions approximating service conditions.

The sheet metal fatigue machines commercially available are not suitable for unsymmetrical bending studies on sheet metal within the 0.010 to 0.040-in. range of thickness normally employed in the manufacture of flat springs. These commercial machines either do not permit testing except under conditions of completely reversed stress or lack sufficient amplitude to permit testing in the stress range corresponding to service conditions. The machine previously used by Gohn and Ellis (2) for unsymmetrical bending studies was built primarily for exploratory studies and could not be operated at speeds in excess of 500 rpm.

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 713.

To permit evaluation of the fatigue characteristics of sheet and strip metal under conditions of unsymmetrical loading, a multi-specimen machine is required capable of being operated at high speeds (2000 to 3000 rpm.) at various mean deflections and with a total throw ranging from zero to approximately 2 in. Under these operating conditions, the deflecting force should always be applied at the same point on the test specimen and wear of running parts must be negligible; otherwise the deflection cannot be translated into terms of uniform stress throughout the life cycle. Starting with the specimen shown in Fig. 1(*a*) which has been used in the sheet metal fatigue studies reported by other investigators (2, 3, 4, 5, 6, 7) and modifying it as shown in Fig. 1(*b*) to permit the use of a deflecting boot, a machine has been designed which will meet these test requirements.

DESCRIPTION OF NEW TESTING MACHINE

The new fatigue testing equipment developed for unsymmetrical bending studies is shown in Fig. 2. This view shows, in addition to the fatigue testing machine, the Plexiglass cover used to enclose moving parts for protection of personnel, the driving motor, and the electronic monitoring system. The machine is shown in greater detail in Fig. 3. It consists essentially of a central inverted T-shaped rail, *A*, supported at one end by a bracket, *B*, and at the other end by a mechanism housing, *C*. Twelve specimens, S_p, may be clamped to each side of the rail as shown in Fig. 3. These specimens extend through hollow rock shafts, *D*, and are oscillated by rocker arms, *E*, each of which drives two specimens by means of a common deflecting

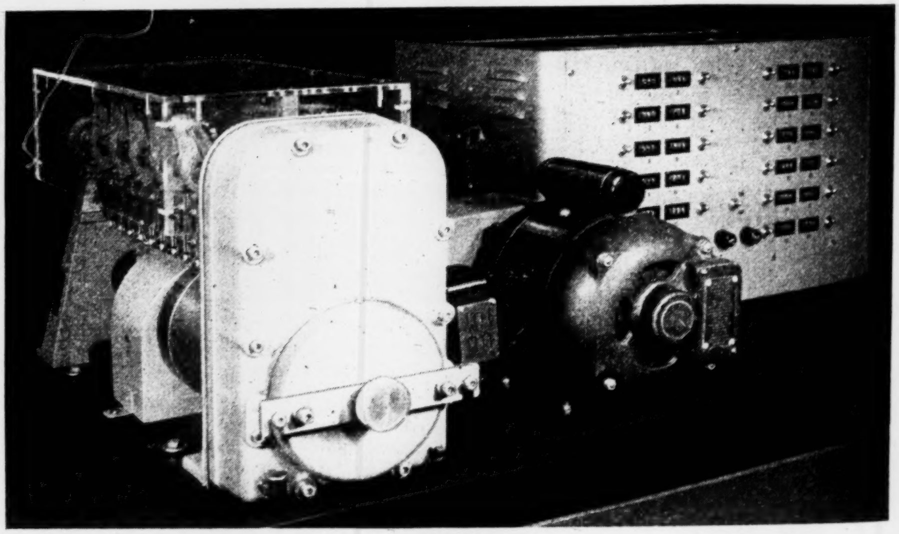

FIG. 2.—Sheet Metal Fatigue Testing Equipment.

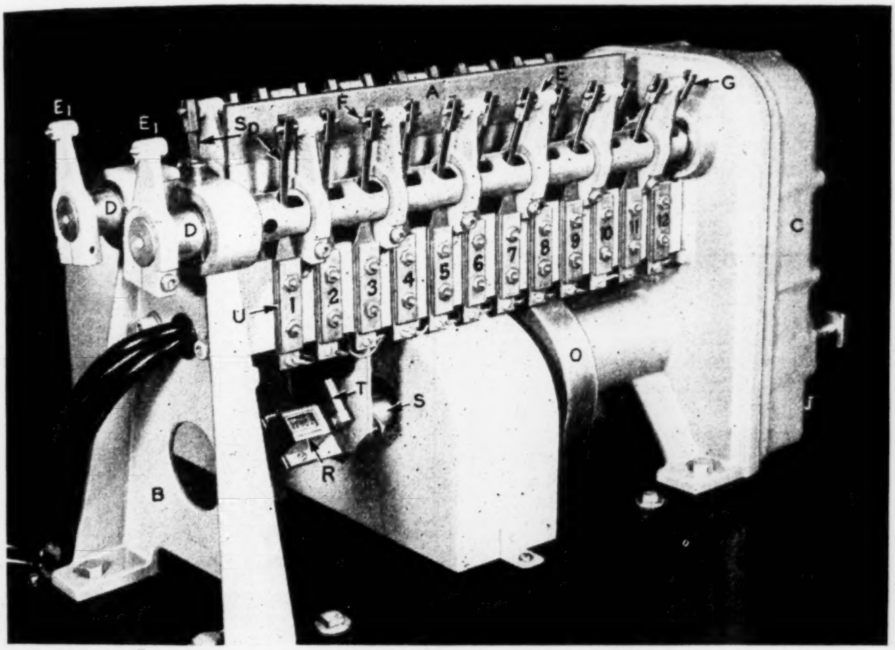

Fig. 3.—Sheet Metal Fatigue Testing Machine.

I
H
I
D
D
J
J
M
L
K
N

Fig. 4.—Sheet Metal Fatigue Testing Machine—Actuating Mechanism.

pin, *F*. To eliminate any end thrust, these pins must be a smooth sliding fit in the U-shaped boots, *G*, fastened on the ends of the test specimens. Windows are cut in the rock shafts *D* to clear the specimens over an angle of ± 30 deg. and to permit an additional displacement of the specimen of 30 deg. for unsymmetrical loading. The location of the rock shaft center is approximately at the 1/3 point of the fatigue test specimen and corresponds to the center of rotation of the end of the specimen. This is essential for high deflections such as those required for unsymmetrical bending studies in sheet metal of the thickness normally used for flat springs. Without this important design feature, the point of loading at maximum deflection would not be fixed but would vary with each increment of deflection.

Inside the mechanism housing (Fig. 4) Pitman arms, *H*, are clamped to the ends of the rock shafts *D*. These Pitman arms carry counterbalances, *I*, which reduce external vibration at the expense of bearing loading. The Pitman arms are driven by two connecting rods, *J*, from a crankshaft which is concealed by the connecting rods. This crankshaft carries an eccentric bushing, *K*, which can be rotated to change the stroke from a minimum of zero to a maximum of 1 in. The eccentric bushing is counterbalanced by weight *L* so as to maintain balance independently of the stroke. The crankshaft also carries a counterbalance *M* and an oil slinger *N*. A fly wheel (*O*, Fig. 3) and a belt pulley (hidden by the guard) are mounted on the outer end of the crankshaft.

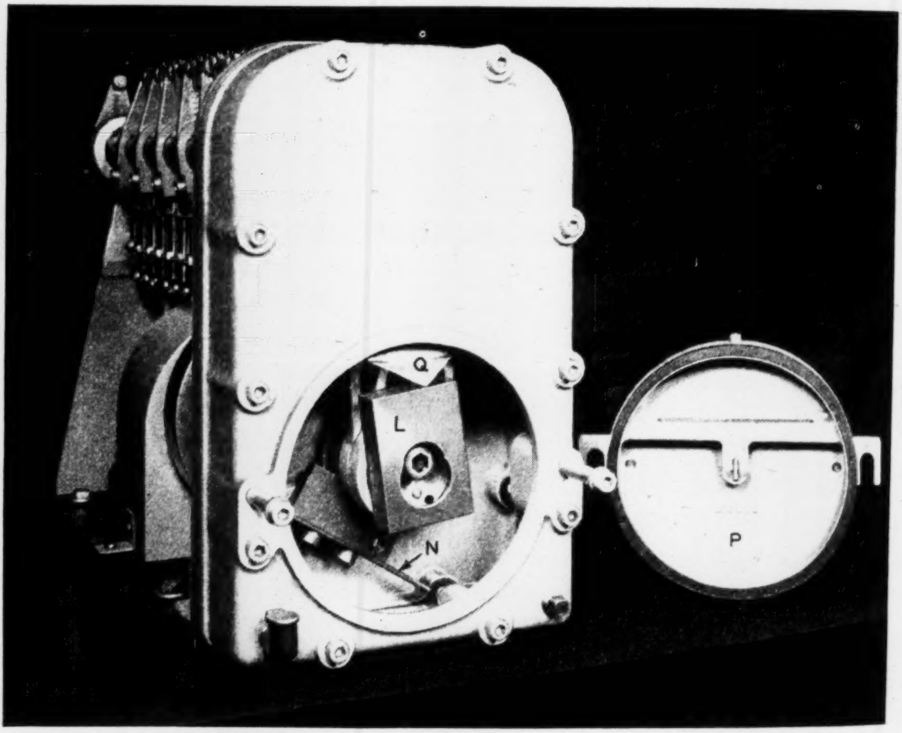

FIG. 5.—Sheet Metal Fatigue Testing Machine Open for Adjustment of Stroke.

Lubrication at the outboard ends of the rock shafts is obtained by means of felt packed oil cups. The rest of the mechanism is lubricated by splash feed. Oil pockets and holes are provided in the rock shaft bearings, the upper ends of the connecting rods and the crankshaft sleeve bearing. The oil slinger (*N*, Fig. 5) throws the oil around inside the mechanism housing. Some of the oil falls into the oil pockets and thus lubricates the bearings. Lubrication of the crank pin is from a horizontal oil pocket in the cover (*P*, Fig. 5) which drains into a recess in the end of the eccentric counterweight (*L*, Fig. 5). From this recess the oil is fed by centrifugal force through drilled passages to the crankpin under each connecting rod. The small dribbler (*Q*, Fig. 5) is necessary to permit oil to fall into the offset recess in the cover, *P*.

By the use of counterweights and the system of lubrication described in the previous paragraph, it has been possible to build a fatigue machine that can be used for unsymmetrical bending fatigue studies at speeds as high as 3000 rpm. At these speeds the lubrication has proved adequate; in fact in operation the oil supply to the bearings maintains a sufficient film so that it has become necessary to install auxiliary spring loaded contacts on the ends of the two rock shafts to provide continuity of the electrical circuit used for specimen monitoring.

Counter Mechanism

As a gear reducer for the mechanical counter (R, Fig. 3) a Telechron motor unit, S, is driven from the end of the shaft by means of a small U-shaped pin. This gives a 1000 to 1 reduction between the main shaft and the Veeder counter R. For increased life an outboard bearing has been built into the clock mechanism.

Monitoring of the individual specimens is accomplished by an electronic counter, shown in Fig. 2. The monitoring circuit is illustrated in Fig. 6. Essentially it consists of individual electrically operated counters which are inactive so long as the grounded circuits are complete through the test specimens. When a test specimen fails, the cold-cathode trigger tube, acting like a relay, permits current to flow to its associated electromagnetic counter each time the cam operated switch (T, Fig. 3) is closed. Thus the monitoring circuit picks up the count only after failure of a specimen and the number of cycles to failure is the difference between the Veeder counter reading and that of the electrical counter.

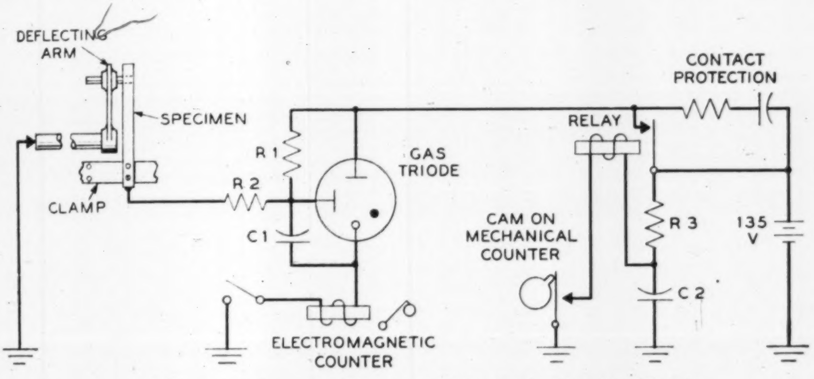

Fig. 6.—Schematic Diagram of Electronic Counter Circuit.

The electronic monitoring circuit was selected instead of the relay monitoring circuit used by Greenall and Gohn (4) to reduce current drain to the point where local dry batteries could be used for the power supply and to permit filtering so that momentary opens at the boot or momentary contacts of the ends of a broken specimen would not produce false counts on the individual electromagnetic counters.

Referring to Fig. 6, the starter anode of the cold cathode tube is momentarily connected to the positive terminal of the battery through the resistance R_1 but is held below firing voltage because the starter anode is also grounded through the resistance R_2 and the test specimen. The condenser C_1 sustains the starter anode potential against microphonic contacts at the boot and against false operations from transient contacts of the broken ends of the test specimen after failure occurs. The resistance R_1 is high enough to prevent any hazard or discomfort to personnel while working with the machine.

When the fatigue specimen breaks, the voltage on the starter anode, no longer restrained by the drain to ground, builds up to a point where the tube is discharged. This causes ionization in the tube permitting a discharge between the main anode and the cathode large enough to operate the electromagnetic counter. To increase the life of these counters, individual switches are provided to permit disconnection after failure of the associated test specimen.

The cam operated switch on the mechanical counter operates a relay once for each 1000 cycles. The relay connects the battery to the system and this permits operation of the individual counters in those positions where specimen breaks have occurred. The duration of relay closure is limited to conserve battery and tube life by operating the relay through discharge of condenser C_2 which is slowly recharged through resistance R_3.

DESCRIPTION OF SPECIMENS AND PREPARATION FOR TESTING

To determine the fatigue characteristics of an alloy in sheet or strip form under various conditions of mean stress, specimens similar to those shown in Fig. 1(*a*) are first prepared by cross milling a group of sheared blanks using a special spiral-fluted contour cutter. Any milling marks left from this operation are removed by lightly stoning the specimens in a direction parallel to the length, care being taken not to destroy the contour during this operation as this would change the l/b ratio.

A group of these specimens, representing the spread of thickness encountered in the lot are then used to determine the load-deflection characteristics of the alloy under test. In this operation the maximum deflection should be at least as large as the greatest deflection used in the fatigue tests. This may be as much as 1.5 to 2 in. depending upon the alloy under test. In these measurements the load is applied at the point of intersection of the extended sides of the tapered section (Fig. 1(*a*)). This is accomplished by drilling a small hole (No. 60 drill or smaller) at this point and using a fine wire supported either from a ball or knife-edge to carry the weight pan. For each deflection the effective moment arm is also determined and from these two measured values the stress is calculated from the basic formula

$$S = \frac{My}{I},$$

which for a rectangular cross-section reduces to

$$S = \frac{6Pl}{bd^2}$$

where:

M = the bending moment in inch pounds,
y = the distance from the neutral axis to the extreme fiber in inches,
I = the moment of inertia in quadratic inches,
S = the stress in pounds per square inch,
P = the load in pounds,
l = the length in inches,
b = the width in inches, and
d = the thickness in inches.

For these studies the effective moment arm is taken as the distance from the point at which the load is applied to the middle of the $\frac{3}{8}$-in. section of uniform stress and the width at that point is used in the preceding calculations. This width is fixed by the machining operation and can be calculated from Fig. 1(*a*)

A curve is then plotted to show the relation between deflection and stress, and this curve, Fig. 7, is used in computing the stresses corresponding to the various maximum and minimum deflections. This relationship approximates a straight line. In general, within the yield strength, the stress corresponding to any set deflection remains essentially constant throughout the duration of the test. This has been verified in previous tests in which the stress-deflection characteristics of the fatigue specimens were determined at different intervals after various numbers of cycles had been applied. In tests on grade A phosphor bronze strip checks on the load-deflection characteristics after 100,000,000 cycles of completely reversed stress at 33,000 psi. showed no measurable difference in the load-deflection characteristics as a result of stressing. Above the yield strength, the stresses shown in Fig. 7 correspond to those calculated from the initial load-deflection measurements. The high stress values undoubtedly fall off somewhat as the specimens are repeatedly stressed above the yield strength, but since this represents a range of academic rather than engineering interest, the authors have not yet studied this phase of the problem.

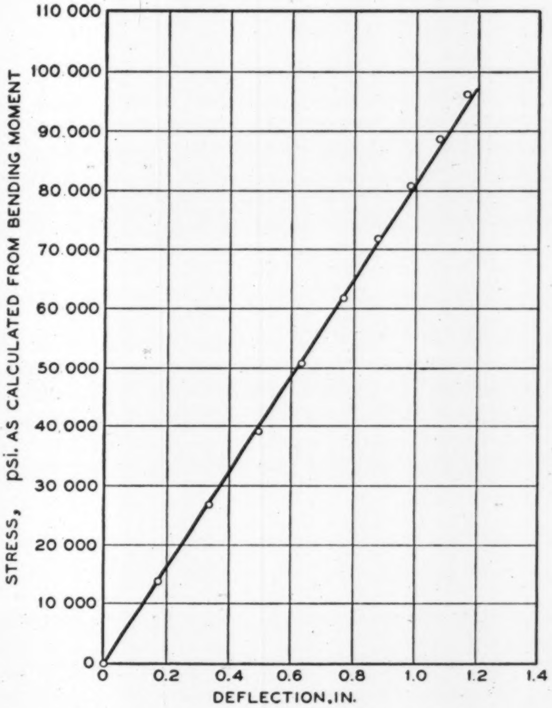

Fig. 7.—Calibration Curve for Determining Stress at Various Deflections.

In preparing the specimens for test, the ends are cut off approximately $\frac{3}{8}$ in. back from the intersection of the tapered sides and a U-shaped boot soldered to the end as shown in Fig. 1(*b*). These specimens are then clamped on the fatigue machine by means of the insulated clamping blocks, *U*, shown in Fig. 3 and the deflection adjusted statically to the approximate test value by varying the eccentric bushing on the crankshaft (*K*, Fig. 4). The mean stress desired is obtained by adjusting the rocker arms *E* to the proper value of deflection while the rock shaft is set at the neutral point of the stroke, after which the machine is ready for the dynamic calibration.

METHOD OF ESTABLISHING DYNAMIC DEFLECTIONS

To determine the deflection at testing speeds accurately an extra rocker arm (E_1, Fig. 3) is mounted at the end of each rock shaft. At the center of the deflecting pin a $\frac{1}{16}$-in. Rockwell hardness ball is cemented in place. A spot of light from a small bulb thrown upon this ball during the operation of the machine will produce a streak of light having a very sharp termination at the extremities of the throw. This movement can be accurately measured with a cathetometer, thus giving a dynamic calibration for the machine. Theoretically, the rocker arms on which the dynamic measurements are made have a different deflection than do those which deflect the test specimens because of the absence of the restoring force exerted by the specimen. However, in actual practice the maximum restoring force is only 2 lb. and this force would cause a deflection of less than 0.0001 in.—a negligible effect. Having determined the range of the deflection, the rock shaft is set so that the calibrating arm is at the neutral point and the final position of the rock shaft arms is then located from the central rail of the machine. This is accomplished by loosening the locking screws on the split collar and rotating the arms on the rock shaft until the deflecting pins have the desired offset. This offset, which can be varied from zero to a maximum of 2 in., can be checked by measuring the displacement from the central rail (Fig. 4) of the machine either by means of a special micrometer or with a Vernier caliper. The stresses corresponding to the minimum and maximum position of the deflecting pins during operation are obtained from the calibration curve (Fig. 7).

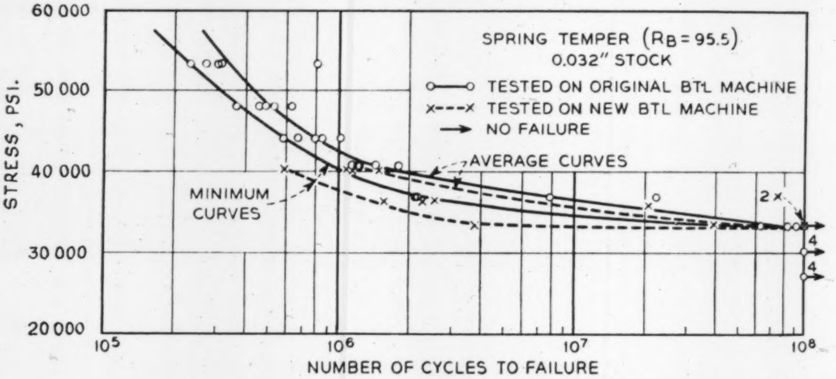

FIG. 8.—Fatigue Characteristics of Grade A (Lot A-3) Phosphor Bronze Strip.

TEST DATA

To make sure that test data obtained on the new fatigue machine were consistent with those obtained by previously accepted methods of test, comparative tests were made on 0.032 in., spring temper grade A phosphor bronze strip[3] on the new machine and on the constant deflection machine previously described by Townsend and Greenall (3). The material used in these studies had the following composition and physical properties:

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[3] Standard Specifications for Phosphor Bronze Sheet and Strip (B 103 - 46), 1946 Book of A.S.T.M. Standards, Part I-B, p. 74.

Composition	
Copper, per cent	94.65
Tin, per cent	4.67
Phosphorus, per cent	0.21
Antimony, per cent	<0.003
Iron, per cent	<0.01
Lead, per cent	<0.01
Zinc, per cent	<0.03

Physical Properties	
Tensile strength, psi.	102 000
Yield strength, 0.01 per cent offset, psi.	66 000
Proportional limit, psi	47 000
Elongation per cent in 2 in.	2.5
Youngs Modulus, psi	15 300 000
Rockwell B hardness	95.5
Fatigue strength at 10^8 cycles of reversed stress, psi.	33 000

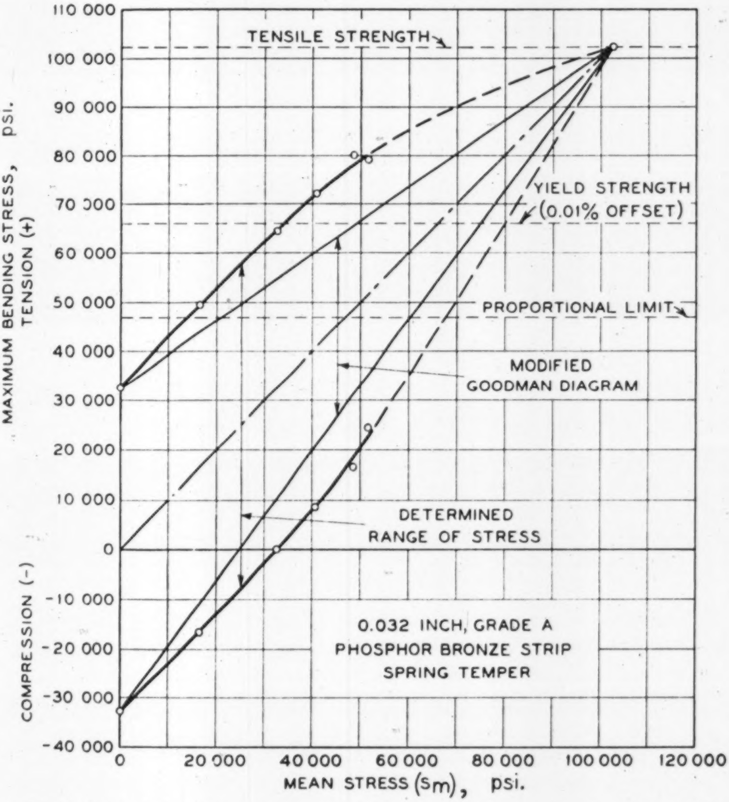

FIG. 9.—Effect of Mean Stress on the Range of Stress in Unsymmetrical Repeated Bending.

The results of the comparative tests on the two testing machines under conditions of completely reversed stress (zero mean stress) are shown in Fig. 8. These data indicate good agreement between the two tests throughout the range of stresses studied. It should be noted that the fatigue strength of this lot of grade A phosphor bronze strip at 100,000,000 cycles of completely reversed stress was higher than that previously reported by Greenall and Gohn (4) or by Burghoff and Blank (7) for "as rolled" material but not as high as that reported by Price and Bailey (6) for polished specimens. The latter investigators also terminated their tests after 50,000,000 cycles.

Data obtained on the new machine from unsymmetrical bending studies on the grade A phosphor bronze strip are shown in Fig. 9. These data indicate that when the maximum stress amplitude is below the yield strength of the material the safe range of stress is essentially constant for bending fatigue tests. This agrees with the previous findings of

Gohn and Ellis (2) and is more clearly illustrated by Fig. 10 which shows the results of the present tests and previously reported data on two other strip materials. At maximum stress amplitudes above the yield strength, the safe range of stress falls off in the direction predicted by the Goodman analysis.

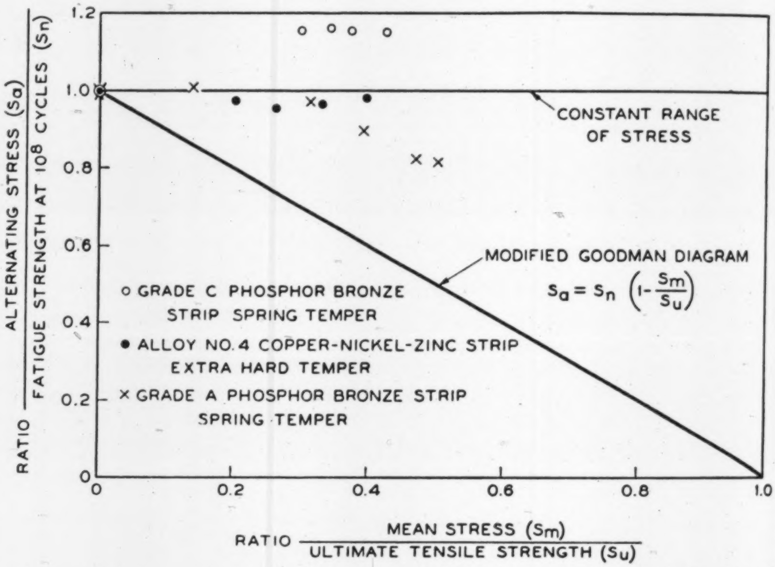

FIG. 10.—Alternating Stress - Mean Stress Diagram for Ranges of Repeated Bending Stresses

Summary

A multi-specimen fatigue machine has been developed which will permit the testing of 24 strip specimens in bending at various mean stresses ranging from zero to a maximum corresponding to a deflection of 2 in. As many as twelve different mean stresses may be used simultaneously with any given alternating stress superimposed thereon provided the total deflection (mean plus alternating component) does not exceed 2 in. Counterweights added to reduce the unbalanced loads and adequate lubrication permit operating the fatigue testing machine at speeds as high as 3000 rpm.

Satisfactory agreement was obtained in one series of tests for the fatigue characteristics of grade A phosphor bronze strip as determined at zero mean stress on the new fatigue machine as compared with the results of fatigue tests on the same material when tested on the fatigue machine described by Townsend and Greenall (3). For the grade A phosphor bronze strip, the safe range of stress at 10^8 cycles of alternating stress was constant for maximum stress amplitudes not exceeding the yield strength. This agrees with the previous findings of Gohn and Ellis (2) on two other non-ferrous strip metals tested in bending at various mean stresses. Above the yield point, the safe range of stress decreased in the direction predicted from the Goodman diagram.

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(1) James O. Smith, "The Effect of Range of Stress on Fatigue Strength of Metals," *Bulletin No. 334*, Vol. 39, No. 26, Engineering Experiment Station, University of Illinois (1942).

(2) G. R. Gohn and W. C. Ellis, "The Fatigue Characteristics of Copper-Nickel-Zinc and Phosphor Bronze Strip in Bending Under Conditions of Unsymmetrical Loading," *Proceedings*, Am. Soc. Testing Mats., Vol. 47, p. 713 (1947).

(3) J. R. Townsend and C. H. Greenall, "Fatigue Studies of Non-Ferrous Sheet Metals," *Proceedings*, Am. Soc. Testing Mats., Vol. 29, Part II, p. 353 (1929).

(4) C. H. Greenall and G. R. Gohn, "Fatigue Properties of Non-Ferrous Sheet Metals," *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part II, p. 160 (1937).

(5) G. R. Gohn and S. M. Arnold, "The Fatigue Properties of Beryllium-Copper Strip and Their Relation to Other Physical Properties," *Proceedings*, Am. Soc. Testing Mats., Vol. 46, p. 741 (1946).

(6) W. B. Price and R. W. Bailey, "Fatigue Properties of Five Cold Rolled Copper Alloys," *Transactions*, Am. Inst. Mining and Metallurgical Engrs., Inst. Metal Div., Vol. 124, p. 271 (1937).

(7) H. L. Burghoff and A. I. Blank, "Fatigue Properties of Some Coppers and Copper Alloys in Strip Form," *Proceedings*, Am. Soc. Testing Mats., Vol. 48, p. 709 (1948).

DISCUSSION

Mr. H. F. Moore.[1]—I was especially interested in the modified Goodman diagram shown in Fig. 10 of the paper. Several proposed modifications of the original Goodman diagram have been proposed, and test data for repeated-torsion tests and for repeated-bending tests show that in some cases the constant range does seem to hold better than the old 1.50 variation from complete reversal to from zero to maximum.

I have no reason to doubt the accuracy of the test here—whether it would hold on thicker material I am not quite so sure. We still have considerable to learn about the formula which we shall use for our Goodman diagram or its modification for larger specimens and I hope that soon we will get some data on that subject.

Mr. T. J. Dolan.[2]—The authors are to be congratulated on the very ingenius machine for testing these small specimens of thin sheet stock that are very difficult to handle.

Their problem in connection with the fatigue properties under varying ranges of stress is a rather important one, and there has been a good deal of discussion in the past about the modified Goodman diagram and other means of predicting fatigue strengths under ranges of stress that are not completely reversed.

As Mr. Gohn knows, I have disagreed with him once or twice on his term "unsymmetrical bending" because, unsymmetrical bending generally is accepted as meaning bending in which the plane of the loads is *not* an axis of symmetry (or principal axis of inertia) of the specimen (and hence lateral bending also occurs).[3] The authors have used the term "unsymmetrical" to imply lack of symmetry of the stress-time pattern with respect to a zero level of stress.

I should like to indicate one possible reason why data for bending such as those presented in the paper may show a constant range of stress for varying mean stresses whereas those tabulated by J. O. Smith[4] for axial load fatigue tests indicate a closer agreement with a modified Goodman diagram.

In the accompanying Fig. 11 the ordinates represent the bending moment on a rectangular beam, divided by the bending moment at the yield point—for a material such as a low carbon steel that has a horizontal tangent at the yield point.[5] The abscissas represent the strain at the yield point.

At the ordinate (and abscissa) of unity, conditions of yielding are reached in the extreme fiber. However, as the bending moment is increased the moment-strain curve deviates very little from a straight line to somewhat higher values of moment. For a rectangular beam the bending moment at which the curve approaches a horizontal asymptote is about $1\frac{1}{2}$ times the bending moment at the yield point.

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[2] Research Professor of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

[3] See for example, Chapter VI of F. B. Seely "Advanced Mechanics of Materials," John Wiley & Sons, New York, N. Y. (1932).

[4] James O. Smith, "The Effect of Range of Stress on Fatigue Strength of Metals, "*Bulletin No. 334*, Engineering Experiment Station, University of Illinois (1942).

[5] See for instance: Discussion by O. Sidebottom and T. J. Dolan of "Effect of Stress Distribution on Yield Points," *Transactions*, Am. Soc. Civil Engrs., Vol. 112, pp. 1230-1238 (1947); or D. Morkovin and O. Sidebottom "The Effect of Non-Uniform Distribution of Stress on Yield Strength of Steel," *Bulletin No. 372*, Engineering Experiment Station, University of Illinois (1947).

It will be noted that the majority of tests plotted in Fig. 9 of the paper were at stresses above the proportional limit of the material. Since this material does not have a definite yield point, the moment-strain curve would deviate even less markedly from a straight line than the curves in Fig. 11 as the bending moments are increased above the proportional limit. However, if one were to obtain a bending moment of, say, $1\frac{1}{4}$ times the yield point in Fig. 11, the computed (nominal) stress would be $1\frac{1}{4}$ times the yield point stress, whereas the true (or actual) stress in the material would remain at the level of the yield point as indicated by the horizontal line whose ordinate is unity.

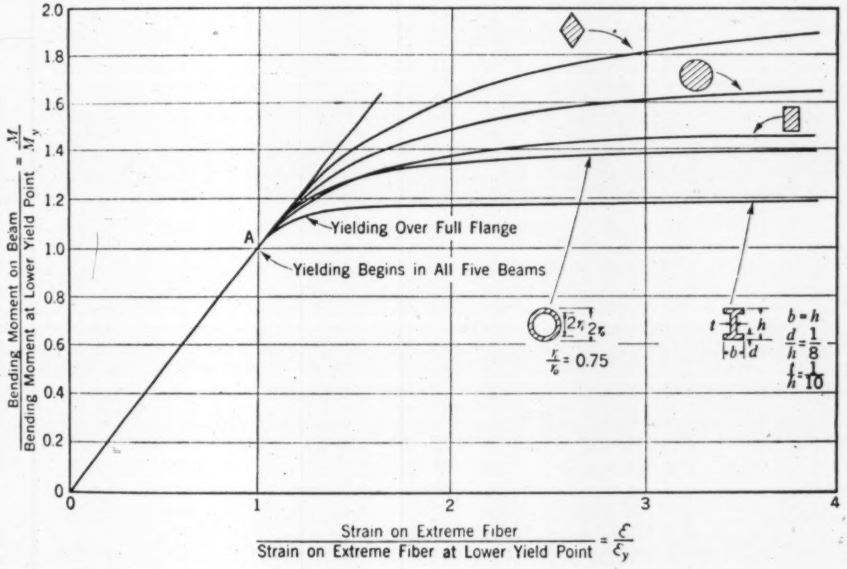

FIG. 11.—Theoretical Moment-Strain Diagrams for Metal with a Definite Point σ_y

In the paper the bending moments have been converted to nominal flexural stresses and plotted as ordinates in Fig. 9, whereas the true stresses may have been somewhat lower than these nominal stresses. If, in Figs. 9 and 10, one could determine the true alternating stresses, they would be lower than the nominal stresses by amounts depending upon the magnitude of the mean stress, and might thus show a decrease in allowable range of stress as the mean stress was increased.

I offer this merely as a possible explanation for some differences in the literature between tests in bending which indicate a constant range of stress for fracture at different mean stresses and those tests under axial load which indicate that smaller alternating components of stress will produce fracture if the mean stress is increased.

MR. G. R. GOHN (*author's closure*).—In answer to the question raised by Mr. Moore, we have no brief either for the original Goodman diagram or for the modified Goodman diagram. We are trying to get data which can be used in our designs without any factor of safety and we want to know where the minimum and maximum stress amplitudes lie for a given mean stress. Perhaps after enough data are accumulated on a number of materials we can develop a theory to fit the data.

Mr. Dolan has offered a very reasonable explanation as to why results such as ours obtained from bending tests differ from the results reported by J. O. Smith for axial load tests. Perhaps others may be induced to continue studies of this type so that this explanation may be verified. Some of my mathematically inclined friends were asked to compute the stresses in the test specimens for various deflections known to be sufficiently large to stress the phosphor bronze above the yield point. They have reported that the difference between the calculated stress and the corresponding value as shown in Fig. 9 differed by no more than the deviation of the stress-strain curve from the straight line representing the modulus of elasticity. In the range of stresses used in these tests, this difference was quite small. It would, however, be somewhat greater on a true-stress true-strain basis, but the difference would be less for a material like phosphor bronze than for the mild steel discussed by Mr. Dolan.

THE TIME DELAY FOR THE INITIATION OF PLASTIC DEFORMATION AT RAPIDLY APPLIED CONSTANT STRESS*

By D. S. Clark[1] and D. S. Wood[1]

Synopsis

The design and construction of a special rapid-load testing machine is described with which tensile loads may be applied to a specimen within 5 milliseconds and longer. Tests made on an annealed low-carbon steel are presented and discussed in detail. It is shown that a definite time delay is required for the initiation of plastic deformation in this material and that this delay time depends upon the applied stress. Experimental results obtained on five materials for which the stress-strain curve does not exhibit a definite yield point are briefly presented. No time delay for the initiation of plastic deformation is observed for these materials. It is concluded that the time delay is associated with the yield point of mild steel.

Many investigators have studied the effects of rate of application of load and rate of deformation on the mechanical properties of metals and alloys. Most of these investigations were made at rates that may be obtained with screw-driven testing machines. A few of the more recent studies of this type are those of Winlock and Leiter (**1**, **2**)[2], Davis (**3**), Elam (**4**), and Miklowitz (**5**). Mann (**6**, **7**), Clark and Datwyler (**8**), Clark (**9**), Manjoine and Nadai (**10**), Parker and Ferguson (**11**), DeForest, MacGregor, and Anderson (**12**), and others have studied these effects at the much higher rates of deformation obtained in tension impact tests. However, Clark and Duwez (**13**) have shown that the yield stress cannot, with any degree of reliability, be determined from force-time curves obtained in a tension impact test. This is related to the effects of the elastic and plastic strain waves which propagate through the specimen and the elastic waves in the force-measuring device.

In addition to the effects of rate of application of load and rate of deformation, the mechanical properties of materials are functions of time explicitly. The time effect has been extensively studied in creep and stress-rupture tests at elevated temperatures, and at very low stresses in studies of the "anelastic" or "elastic after working" phenomena. However, very few studies of the time effect have been made at stresses exceeding the room temperature static elastic limit.

The purpose of this paper is to describe equipment which has been developed for making tension tests in which the stress is applied rapidly to values above the static elastic limit and maintained at a specified stress and to present some of the experimental results that have been obtained. The results of tests are given for several alloys, but the greatest interest is attached to a material for which the static stress-strain curve shows a distinct yield point.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] Associate Professor of Mechanical Engineering and Research Assistant, respectively, California Institute of Technology, Pasadena, Calif.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 734.

Equipment

Rapid-Load Testing Machine:

In this investigation it was desired to apply a tensile load in as short a time as possible and in such a way that the stress would be substantially uniform throughout the gage length of the specimen at any given instant. The required load-time relation consists of a continuous increase of load over a short finite period of time, followed by a period of indefinite length during which the load remains constant at the maximum value attained during the test. The length of the specimen must be short enough and the rate or rise of load low enough so that the stress at any given instant is uniform over the gage length of the specimen to a close approximation. The term "rapid loading" is used by the authors to distinguish this type of loading from impact loading. In the latter case the stress distribution is not uniform along the gage length of the specimen.

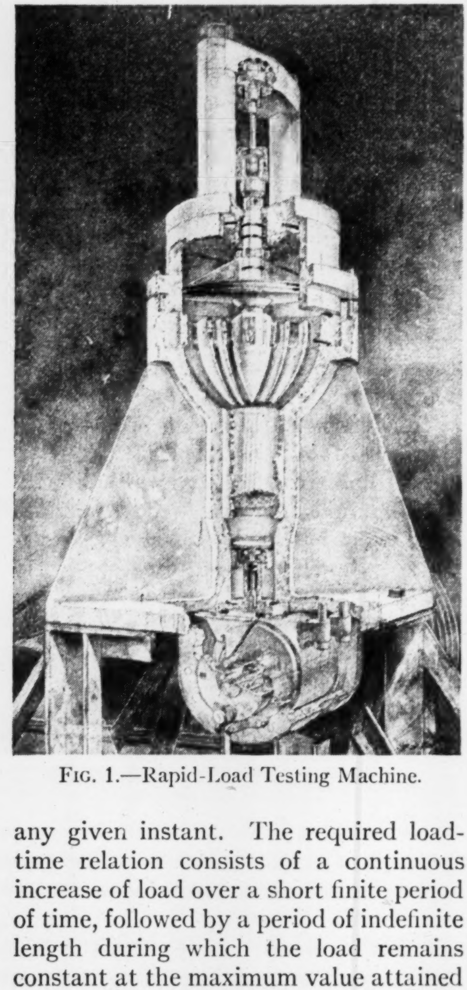


Fig. 1.—Rapid-Load Testing Machine.

A simple mechanical arrangement which will produce a load-time relation of the desired form is a critically damped vibratory system having one degree of freedom. If the mass of such a system is subjected to a step function force, the force in the spring increases in a continuous manner and reaches the applied force in a minimum of time without overshooting. Critical damping is obtained when

$$C = 2\sqrt{KM} \quad \ldots\ldots\ldots (1)$$

where:

C = coefficient of viscous damping,
K = spring constant, and
M = mass of the system.

If a force, F_0, is suddenly applied to the mass at the time $t = 0$, then the force, F, in the spring is given by

$$F = F_0 \left[1 - \left(1 + \frac{t}{\alpha} \right) e^{-(t/\alpha)} \right] \ldots (2)$$

where:

$$\alpha = \sqrt{\frac{M}{K}} \quad \ldots\ldots\ldots (3)$$

and e is the base of natural logarithms. Since the spring force, F, approaches the applied force, F_0, asymptotically, it is desirable to adopt some convention to

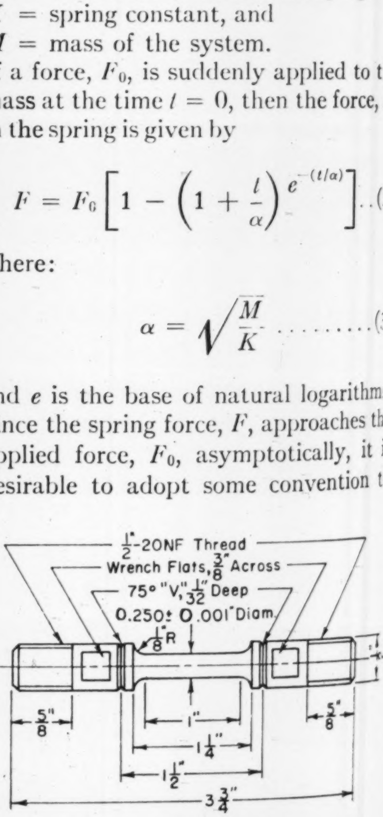


Fig. 2.—Test Specimen.

specify the total rise time, T. One such convention is the time between the intersections of the maximum slope tangent to the curve of F *versus* t given by Eq. 2 with the coordinate lines $F = 0$ and $F = F_0$. It can be shown that this time is given by

$$T = e\alpha \qquad (4)$$

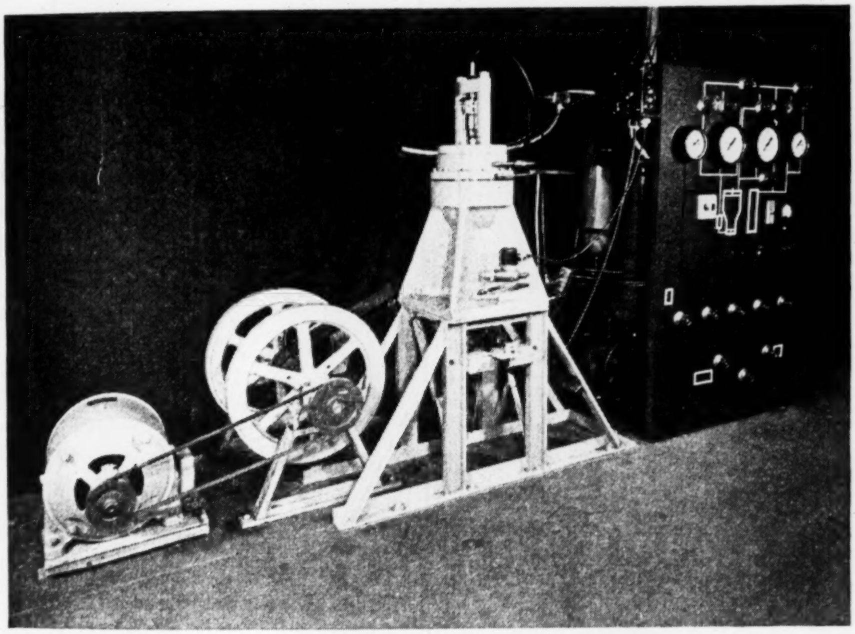


FIG. 3.—General View of Equipment.

Actually F reaches between 75 and 80 per cent of F_0 in the time T. The rapid-load testing machine described in this paper was designed to approximate the simple system discussed above, with the test specimen forming a part of the spring. A view of the machine is shown in Fig. 1. The test specimen (Fig. 2) is supported in the upper portion of the machine by spherical seats. A loading piston is attached to the specimen by a piston rod and spherical seats. Air pressure in the upper portion of the loading piston cylinder provides the load. Below the loading piston is a chamber completely filled with a glycerine-water mixture. This fluid chamber is closed at its lower end by a small actuating piston. Within the fluid chamber is the damping unit, consisting of a nest of small tubes through which the fluid flows when the two pistons and fluid move downward during loading. The actuating piston is controlled by a linearly sliding actuating cam. The upper surface of the cam, on which the actuating piston is supported by means of the actuating plunger, is divided into two horizontal surfaces at different levels connected by a short surface inclined at 45 deg. The cam, operating as a Scotch yoke, executes a single stroke when a rotary-driving mechanism is triggered. The cam speed is controlled by armature voltage control of the direct-current motor of the driving mechanism. Two flywheels are incorporated in the drive to maintain constant rotational speed while the cam is in motion.

The machine is operated as follows: Initially the air and fluid pressures are equalized. Then, at any desired time, the cam mechanism is actuated. As the sloping portion of the cam surface passes under the actuating plunger, the actuating piston moves downward, releasing the fluid pressure and thus loading the specimen. The cam speed determines the rate of application of load for all rates up to a certain maximum. If the cam speed is greater than that corresponding to the maximum possible rate of loading, the actuating plunger will not follow the sloping cam surface. This mode of operation is called "free loading," and the load-time relation to which the specimen is subjected is of the form given by Eq. 2. During the loading period the viscous flow of the fluid through the damping unit provides the necessary damping of the system. After the fluid pressure has been completely released, the constant preset air pressure above the loading piston maintains the load acting on the specimen at a constant value, except in certain instances which are discussed below. Figure 3 shows the machine, together with the driving mechanism and air and fluid control panel.

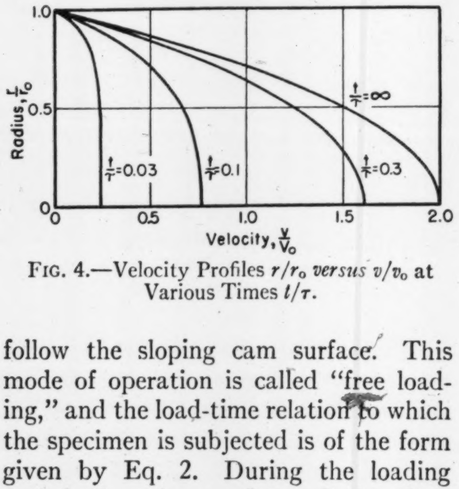


FIG. 4.—Velocity Profiles r/r_o *versus* v/v_o at Various Times t/τ.

All of the members of the machine which support the load, including the test specimen, form the equivalent spring of the system. The equivalent spring constant, K, for the rapid-load testing machine was computed to be about 500,000 lb. per in. when a steel specimen is used. The equivalent mass, M, of the machine is given by

$$M = \Sigma m\left(\frac{v}{v_1}\right)^2 \qquad (5)$$

where m is the actual mass of any portion of the machine, the motion of which is coupled with that of the loading piston, and v/v_1 is the ratio of the velocity of the mass element, m, to the velocity of the loading piston. Using Eq. 5, M was computed to be $\frac{540 \text{ lb.}}{g}$ where g is the acceleration due to gravity.

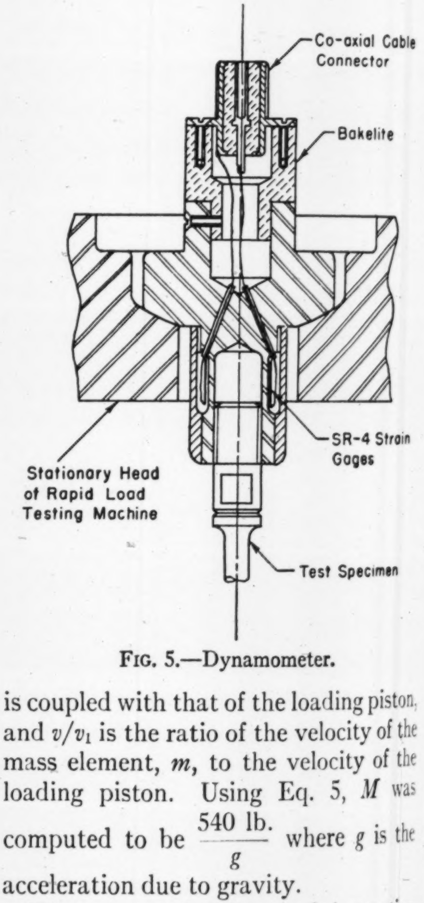


FIG. 5.—Dynamometer.

The cross-sectional area of the portion of the fluid chamber which contains the damping unit and the actuating piston is one tenth the area of the loading piston. The resulting ten-fold increase of the motion of the actuating piston and the ten-fold reduction in the force acting on it facilitate proper control of loading by the cam. Also the increased fluid velocity through the damping unit allows critical damping to be obtained within a reasonably short length of the tubes. These advantages are obtained at the expense of increased equivalent mass.

If steady state viscous flow takes place in the damping unit, the damping coefficient, C, is given by

$$C = 8\,\frac{L\mu}{r_0^2}\,\frac{A_1^2}{A} \quad \ldots\ldots\ldots (6)$$

where:

L = length of the tubes,
μ = absolute viscosity of the fluid,
r_0 = inside radius of the tubes,
A_1 = area of the loading piston, and
A = total cross-sectional area of the tubes.

Actually the flow in the damping unit is not steady flow, so Eq. 6 does not strictly apply. However, it can be shown that if the inside tube radius, r_0, is small enough, steady flow conditions can be obtained in a time which is small compared to the rise time, T. In this case Eq. 6 will provide a good approximation to the coefficient of viscous damping.

The tube radius, r_0, that will insure steady flow within a sufficiently short time compared to the rise time, T, can be selected by means of the following analysis. A circular pipe filled with a stationary viscous fluid is suddenly subjected to a pressure difference, p, across its ends. The pressure is then maintained constant. It is required to investigate the resulting flow as a function of time and to determine the time required to reach steady flow conditions. The following assumptions are made to facilitate the treatment of the problem:

(1) The length of the pipe is much greater than its diameter, hence, end effects may be neglected and the stream lines are straight and parallel to the pipe axis, and

(2) The fluid is incompressible.

The boundary conditions to be satisfied are:

(1) The velocity, v, is always zero at the pipe wall, $r = r_0$,

(2) The velocity is everywhere zero at the time $t = 0$, and

(3) At the time $t = 0$, a pressure difference, p, is applied across the ends of the pipe and is constant thereafter.

The equation of motion of the fluid is

$$\frac{\partial v}{\partial t} - \frac{\mu}{\rho}\left[\frac{\partial v^2}{\partial r^2} + \frac{1}{r}\,\frac{\partial v}{\partial r}\right] = \frac{p}{L\rho} \quad \ldots (7)$$

where r is the radial position of any fluid particle, ρ is the fluid density, and the other terms have been previously defined. A solution of Eq. 7 which satisfies the boundary conditions is

$$\frac{v}{V_0} = 2\left[\left\{1 - \left(\frac{r}{r_0}\right)^2\right\} - 8\sum_{n=1}^{\infty} e^{-\gamma_n^2(t/\tau)}\,\frac{J_0(\gamma_n(r/r_0))}{\gamma_n J_1(\gamma_n)}\right] \quad \ldots (8)$$

where V_0 is the average fluid velocity for steady flow, J_0 and J_1 are Bessel functions of the first kind of order 0 and 1 respectively, γ_n are the roots of J_0 in ascending order of magnitude, and

$$\tau = \frac{\rho r_0^2}{\mu} \quad \ldots\ldots\ldots\ldots (9)$$

is a characteristic time constant of the system. Velocity distributions in the pipe for several values of the time parameter, $\frac{t}{\tau}$, have been computed from Eq. 8 and are shown in Fig. 4. The steady state parabolic velocity profile is given by the curve marked $\frac{t}{\tau} = \infty$. It is seen that steady flow conditions are nearly reached in the time $\frac{t}{\tau} = 0.3$.

The design constants used for the damping unit were

$\rho = \frac{0.045}{g}$ lb. per cu. in. $= 1.17 \times 10^{-4}$ lb. in.$^{-4}$ sec.^{2},

$\mu = 600$ centipoises $= 8.7 \times 10^{-5}$ lb. in.$^{-2}$ sec. (96 per cent glycerine-water mixture). Using Eq. 9 and the criterion $\frac{t}{T} = 0.3$, and choosing a tube radius (r_0) of 0.0395 in., the time to reach steady flow is found to be $t = 0.63$ millisec. This time is small compared to the rise time $T = 4.6$ millisec. computed by Eqs. 3 and 4 using the values of K and M given above. Therefore r_0 has been chosen to be small enough so that the coefficient of viscous damping, C, may be computed from Eq. 6 to a good approximation.

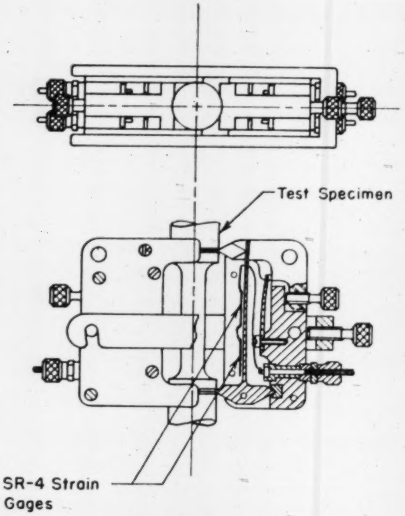


FIG. 6.—Extensometer.

The value of C required for critical damping is given by Eq. 1. For a steel specimen this is 1.67×10^{3} lb. sec. per in. The design of the machine is such that the value of C obtained from Eq. 6 can be made equal to the value given by Eq. 1 by proper choice of the proportions of the glycerine-water mixture, thus providing critical damping. The values of C obtainable in this way vary from approximately 3×10^{3} lb. sec. per in. to 3 lb. sec. per in. when the mixture is varied from 100 per cent glycerine to 100 per cent water respectively.

The rapid-load testing machine is designed to apply any load up to a maximum of 10,000 lb. to the test specimen. The desired load is obtained by proper choice of the operating air pressure. Strain in the specimen is limited to a maximum of 5 per cent by the limited travel of the actuating piston.

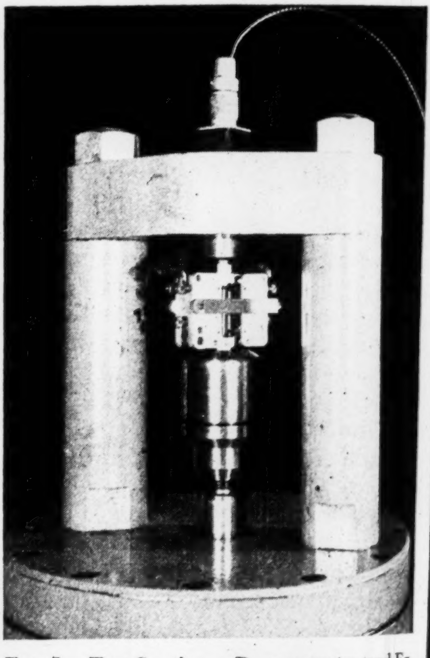
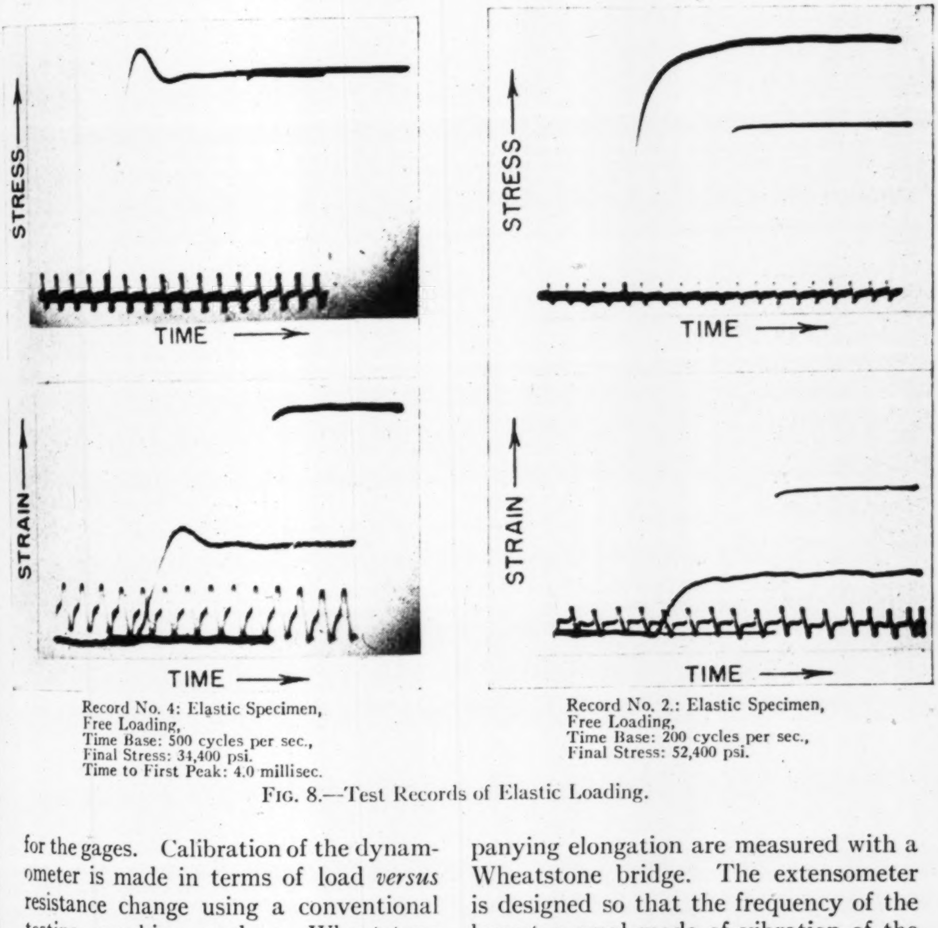


FIG. 7.—Test Specimen, Dynamometer, and Extensometer in Rapid-Load Testing Machine.

Instrumentation:

The load and elongation of the test specimen are measured as functions of time during each test. A dynamometer and an extensometer employing resistance-sensitive wire strain gages, together with suitable cathode-ray oscilloscope equipment, are used for the measurements. The dynamometer shown in Fig. 5 forms the upper specimen grip and incorporates a spherical seat. Baldwin Southwark SR-4 gages are cemented to the hollow cylindrical section between the spherical seat and the specimen threads. A protective cover is provided for the gages. Calibration of the dynamometer is made in terms of load *versus* resistance change using a conventional testine machine and a Wheatstone bridge.



Record No. 4: Elastic Specimen,
Free Loading,
Time Base: 500 cycles per sec.,
Final Stress: 34,400 psi.
Time to First Peak: 4.0 millisec.

Record No. 2.: Elastic Specimen,
Free Loading,
Time Base: 200 cycles per sec.,
Final Stress: 52,400 psi.

FIG. 8.—Test Records of Elastic Loading.

The extensometer, shown in Fig. 6, consists of two essentially identical units clamped together across the test specimen. Two knife edges in each unit engage "V" grooves in the specimen shoulders. Each unit contains a thin steel beam which is bent elastically by elongation of the specimen. Two 500-ohm SR-4 gages are cemented to the tension side of each of these beams. The extensometer is calibrated in a fixture with which known changes of length may be applied to it by means of a micrometer screw. The resistance changes accompanying elongation are measured with a Wheatstone bridge. The extensometer is designed so that the frequency of the lowest normal mode of vibration of the beams is 1000 cycles per sec. A view of the test specimen, dynamometer, and extensometer mounted in the rapid-load testing machine is shown in Fig. 7. The lower specimen grip containing a spherical seat is also shown.

The dynamometer and extensometer are connected in conventional bridge circuits which are energized by batteries and contain provisions for introducing known resistance changes as a means of calibrating the records. The recording system consists of two identical channels. Each channel contains a pre-amplifier, RCA Type 327 A cathode-ray oscilloscope, special single sweep generator, time calibration oscillator, and a camera. The amplifying system is direct coupled, and sweep times ranging from 1 millisec. to 10 sec. may be obtained. Records are made on 35-mm. film using f:1.5 lenses. Each record consists of three oscilloscope traces on one film, namely,

1. The time calibration obtained by means of a trace of a wave of known frequency;
2. The vertical step calibration trace corresponding to a known resistance change in the dynamometer or the extensometer;
3. The force or elongation trace produced in the test.

The three traces occur within a period of about 30 sec.

Statistical studies of controlled calibration experiments using this recording equipment indicate that the uncertainty in stress and strain measurements is not more than 4 per cent. The uncertainty in time measurements is about 1 per cent. An absolute error of not more than 10 per cent may occur in measurements of plastic strain because the strain is computed from the extensometer records neglecting any plastic strain which may occur in the fillets of the specimen. However, the static stress-strain relations for the materials tested were determined in such a way that the same error was introduced. Therefore, the difference between strain determined from rapid-load tests and strain determined in static tests is not subject to this error. An experimentally determined correction was made in all tests for the elastic strain occuring in the fillets and shoulders of the specimens.

Experimental Performance of the Rapid-Load Testing Machine:

To check the actual performance of the machine, several tests were made using a hardened alloy steel specimen stressed within its elastic range. The actuating cam of the machine was operated at such a speed that "free loading" occurred. Photographic reproductions of the records from two such tests are shown in Fig. 8. In Fig. 9 these two load-time records are plotted quantitatively and compared with the theoretical curve given by Eq. 2. For record No. 4 the viscosity of the fluid in the machine was about 400 centipoises while in record No. 2 it was about 1000 centipoises. Since the theoretical viscosity for critical damping is 600 centipoises, as given above, record No. 4 should show less than critical damping and record No. 2 more than critical damping. Figure 9 shows the experimental verification of this conclusion. From these results it is evident that a close approximation to the critical damping can be obtained by proper adjustment of the fluid viscosity.

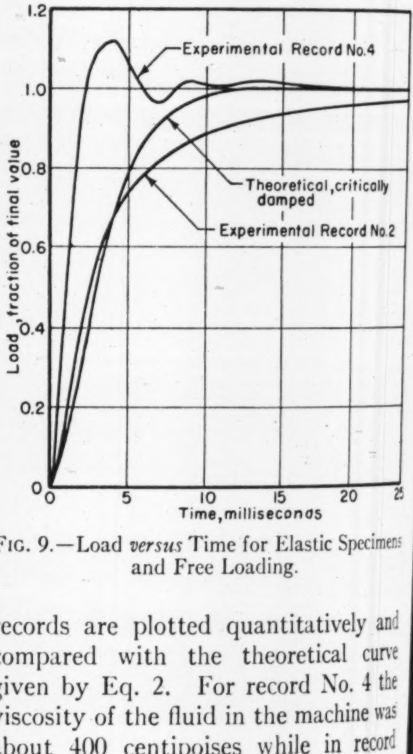


FIG. 9.—Load *versus* Time for Elastic Specimens and Free Loading.

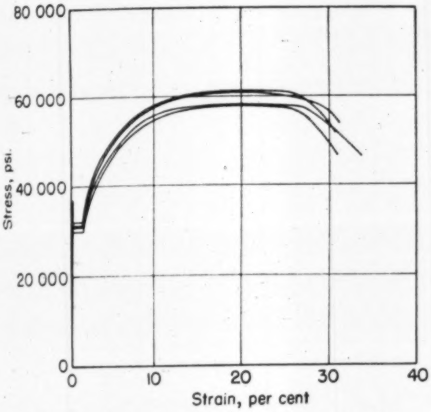


FIG. 10.—Static Stress *versus* Strain for 0.19 per cent Carbon Annealed Steel.

EXPERIMENTAL RESULTS

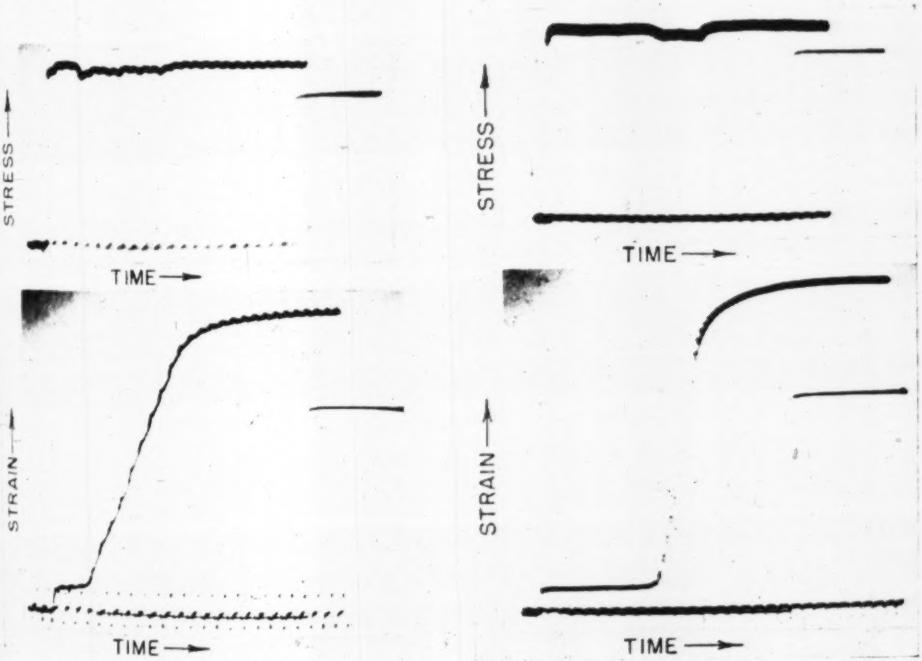
Annealed Low-Carbon Steel:

A series of rapid-load tests was made on a 0.19 per cent carbon annealed steel for which the mill analysis is as follows:

Carbon	0.19 per cent
Manganese	0.43 per cent
Phosphorus	0.018 per cent
Sulfur	0.046 per cent
Silicon	0.07 per cent

This material was hot rolled to bars $\frac{5}{8}$ in. in diameter from a single billet. Specimen blanks 4 in. long were cut from the bars and annealed by heating to 1625 F. for 2 hr. in a Leeds & Northrup Vapocarb furnace. They were furnace cooled, requiring approximately 12 hr. to reach room temperature. Specimens were machined from the annealed blanks in a lathe. Four static stress-strain curves are shown in Fig. 10.

The rapid-load tests were made at a controlled rate of loading of approximately 5×10^6 psi. per sec. The stresses applied ranged from about 37,000 psi. to about 50,000 psi. Thus the time to reach constant stress was 10 millisec. or less in all tests.



Record No. 33: 0.19C Annealed Steel
Time Base: 50 cycles per sec.
Stress: 43,300 psi.
Loading Rate: 5×10^6 psi. per sec.
Calculated Strain: 1.62 per cent
Plastic Strain Delay Time: 0.056 sec.

Record No. 43: 0.19C Annealed Steel
Time Base: 20 cycles per sec.
Stress 39,400 psi.
Looding Rate: 5×10^6 psi. per sec.
Calculated Strain: 1.62 per cent
Plastic Strain Delay Time: 0.47 sec.

FIG. 11.—Test Records—0.19 per cent Carbon Annealed Steel.

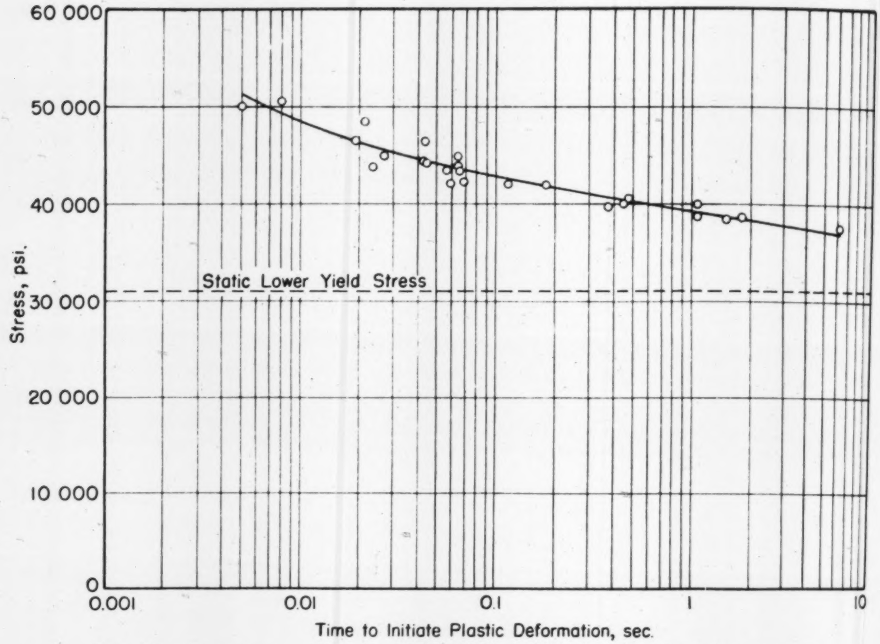


FIG. 12.—Stress *versus* Time to Initiate Plastic Deformation for 0.19 per cent Carbon Annealed Steel.

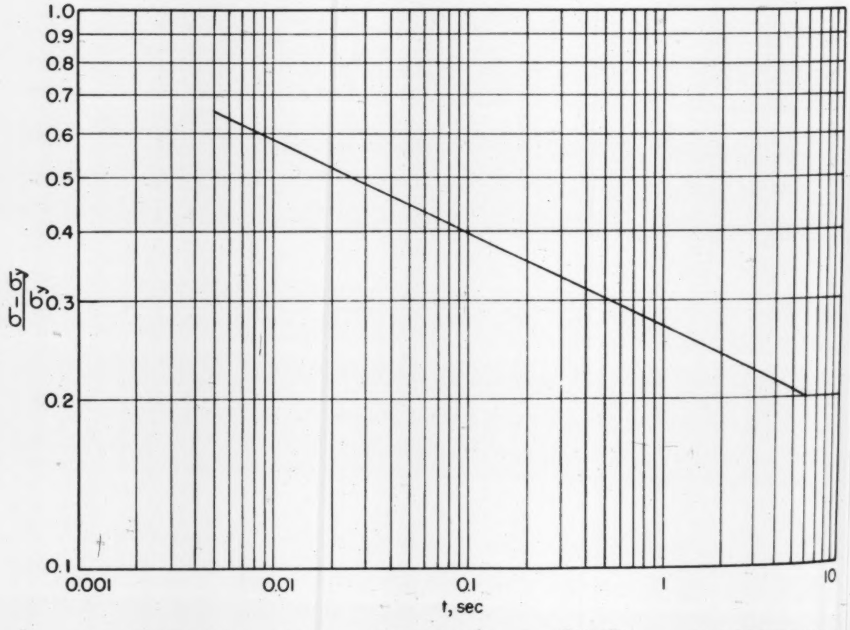


FIG. 13.—Experimental Curve of Fig. 12 Plotted as $\frac{\sigma - \sigma_y}{\sigma_y}$ *versus* t—0.19 per cent Carbon Annealed Steel.

Photographic reproductions of the test records from two of these tests are shown in Fig. 11. It is apparent from these records that a definite period of time is required for the initiation of plastic deformation at a substantially constant stress. This confirms the results of a preliminary investigation made by Duwez, Martens, and Clark (14). Initially the elongation increases elastically as the load is applied. Both the load and elastic elongation remain constant for a well-defined period of time, then deformation begins abruptly and progresses at a constant rate for some time, after which the rate gradually decreases. The load decreases slightly when plastic deformation begins, but remains approximately constant during the period of the constant plastic deformation rate. At the end of that period the load rises again to its original constant value.

Experimental points of "stress *versus* time to initiate plastic strain" obtained in 25 tests are plotted in Fig. 12. The stress plotted is the constant stress during the period of constant elastic deformation. The time to initiate plastic strain is the time during which the elastic deformation is essentially constant. The line in the figure was drawn through the experimental points by eye. The time to initiate plastic strain is seen to range from 5 millisec. at a stress of about 51,000 psi. to 6 sec. at a stress of about 37,000 psi. The line drawn in Fig. 12 is very nearly represented by the relation $t = 4.0 \times 10^{-4}\left(\frac{\sigma - \sigma_y}{\sigma_y}\right)^{-6.0}$, where t is the time to initiate plastic strain in seconds, σ is the applied stress, and σ_y is the static lower yield stress. The straight line representing this relation in a log-log plot is shown in Fig. 13.

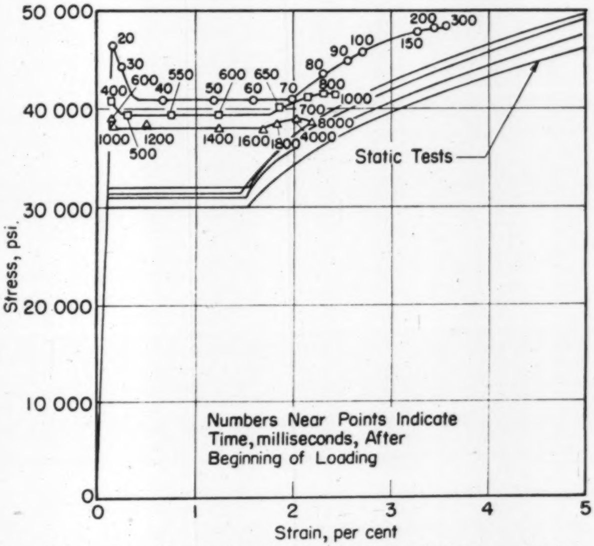


FIG. 14.—Stress *versus* Strain for Three Rapid Load Tests on 0.19 per cent Carbon Annealed Steel.

A time delay for the initiation of plastic deformation has been observed in two tests made with a conventional beam weighing testing machine. A predetermined load was set on the beam scale. This load was applied in a few seconds, bringing the beam to balance without overshooting the load. In one test a stress of 34,300 psi. was applied. After

86 sec. at this stress, the beam suddenly dropped, indicating the initiation of plastic deformation in the specimen. In the second test the time to initiate plastic strain was found in this way to be 615 sec. at a stress of 33,700 psi. A few attempts to obtain additional results of this type were unsuccessful. The plastic strain occurred immediately upon loading, or had not occurred after as long as 30 min. Evidently the phenomenon is difficult to control by the rather crude technique used because of the large difference in the delay time for a small difference in stress.

The drop in load which takes place in the rapid-load tests when plastic deformation begins corresponds to the drop of the beam is a quasistatic test. As in static tests, it is due to the combined effects of the testing machine and the material tested. In the rapid-load tests, the motion of the fluid in the machine during the period of rapid plastic straining causes a viscous friction pressure rise across the damping unit. This raises the fluid pressure below the loading piston, thus decreasing the load acting on the specimen. Several investigators have studied the effects of characteristics of other types of testing machines, particularly the influence of their rigidity upon the drop in load from the upper to the lower yield points in mild steel. Davis (**3**) and Miklowitz (**5**) have studied these effects recently.

It has been recognized for some time that in the yield region of mild steel the strain in the specimen is discontinuous. Duwez, Martens, and Clark (**15**) and Miklowitz (**5**) have shown that to a first approximation the full yield strain appears first at one or more points of stress concentration in the specimen. With continued stretching the boundaries of the plastically deformed regions advance through the specimen until the entire gage length is occupied by the yield strain. At that point the cold hardening region of the stress-strain curve is reached, and subsequent plastic deformation occurs uniformily over the gage length of the specimen. It has also been found (**1, 2, 3, 5**) that the magnitude of the yield strain and the stress at which it takes place are increased by increasing the rate of deformation.

From the records of a given rapid-load test, the path followed by the material in the stress-average strain plane may be determined. Three such stress-strain paths are shown in Fig. 14, where they are compared with the results of static tests. These stress-strain paths are similar to those obtained by Miklowitz (5). It was observed that the horizontal portion of each of the curves of Fig. 14 corresponds to the region of constant plastic deformation rate in the corresponding elongation-time record. Therefore it is reasonable to assume that the observed period of constant plastic deformation rate is a consequence of the propagation of one or more yield strain fronts along the gage length of the test specimen.

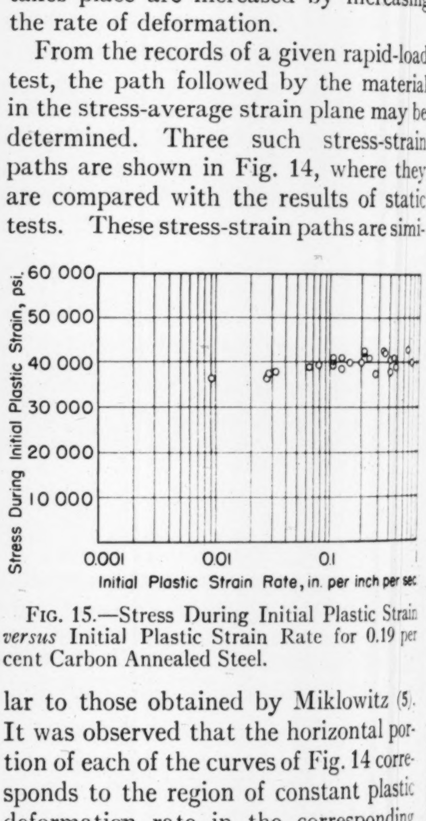


FIG. 15.—Stress During Initial Plastic Strain *versus* Initial Plastic Strain Rate for 0.19 per cent Carbon Annealed Steel.

It would be interesting to determine the rate of propagation of the yield strain front as a function of stress. However, Miklowitz (**5**) has shown clearly that two or more strain fronts may propagate simultaneously, particularly at the higher stresses. Since in the rapid-load tests

TABLE I.—COMPOSITION AND TREATMENT OF TYPE 302 STAINLESS STEEL, S.A.E. 4130 STEEL 24 S-T AND 75 S-T ALUMINUM ALLOYS.

Material	Description	Analysis, per cent													
		C	Mn	Si	S	P	Ni	Cu	Cr	Mo	Fe	Mg	Ti	Zn	Pb
Type 302 stainless steel.....	Tested in as-received condition	0.13	0.62	0.47	0.015	0.020	8.92		18.23						
S. A. E. 4130 steel: Bar No. 1....	Heated at 1650 F. for 30 min., air-cooled, machined	0.26	0.52	0.33	0.025	0.016			0.81	0.16					
Bar No. 2....		0.30	0.52	0.28	0.021	0.020			0.87	0.21					
S. A. E. 4130 steel: Bar No. 7....	Heated at 1650 F. for 30 min., air-cooled. Heated at 1550 F. for 45 min., oil quenched. Tempered at 675 F. for 45 min., oil quenched. Finish ground.	0.27	0.55	0.32	0.026	0.018			0.81	0.16					
Bar No. 8....		0.26	0.53	0.33	0.025	0.038			0.81	0.16					
24S-T Aluminum.........	Heated at 925 F., with 2 hr. 10 min. above 910 F.		0.59	0.14			0.00	4.34	0.02		0.31	1.45	0.02	0.02	0.01
75S-T Aluminum.........	Heated at 910 F. for 1 hr. 10 min Aged at 250 F. for 24 hr. 10 min.		0.12	0.14			....	1.57	0.21		0.31	2.70	0.05	5.62	....

that are reported here, the number of yield strain fronts in any given test is not known, the velocity of propagation of the front cannot be obtained from the test data. Figure 15 is a plot of the stress during initial plastic deformation *versus* the initial plastic deformation rate, expressed as the rate of strain averaged over the gage length. The rather wide scatter of the points, especially at the higher rates of strain, is probably due to multiple yield strain fronts in the specimen.

Other Materials:

Rapid-load tests have also been made on a type 302 stainless steel, S.A.E. 4130 normalized steel, S.A.E. 4130 quenched-and-temperated steel, 24S-T aluminum alloy, and 75S-T aluminum alloy. The analyses of these materials and their treatment is given in Table I. None of these materials exhibit a definite yield point, their static stress-strain curves are everywhere concave downward. The rapid-load tests show that no delay occurs for the initiation of plastic deformation.

A photographic reproduction of the records obtained in one test on the type 302 stainless steel are shown in Fig. 16. Plastic deformation begins during the early stage of load application. The relatively high initial plastic deformation

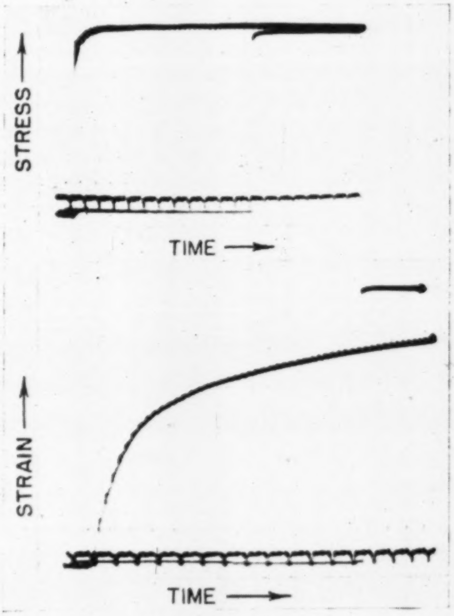


FIG. 16.—Test Records—Type 302 Stainless Steel.

Record No. 13: 18-8 Stainless Steel,
Time Base: 20 cycles per sec.,
Stress: 55,600 psi.
Loading Rate: 5 × 10⁶ psi. per sec.
Max, Strain: 2.2 per cent

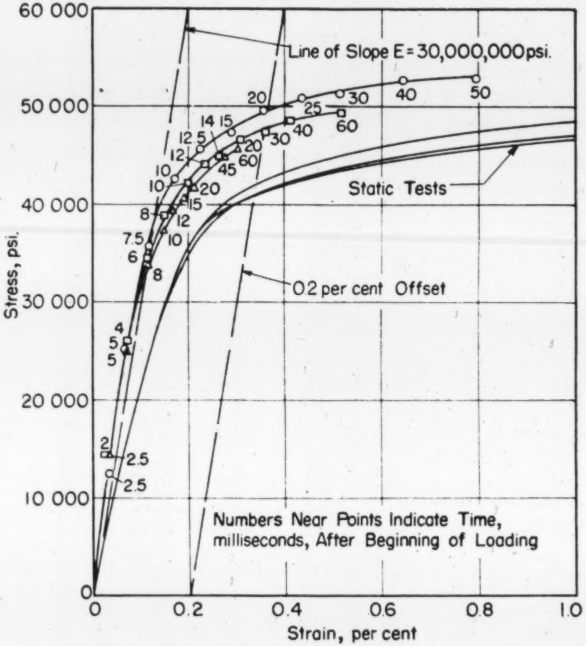


FIG. 17.—Stress *versus* Strain for Three Rapid-Load Tests on Type 302 Stainless Steel.

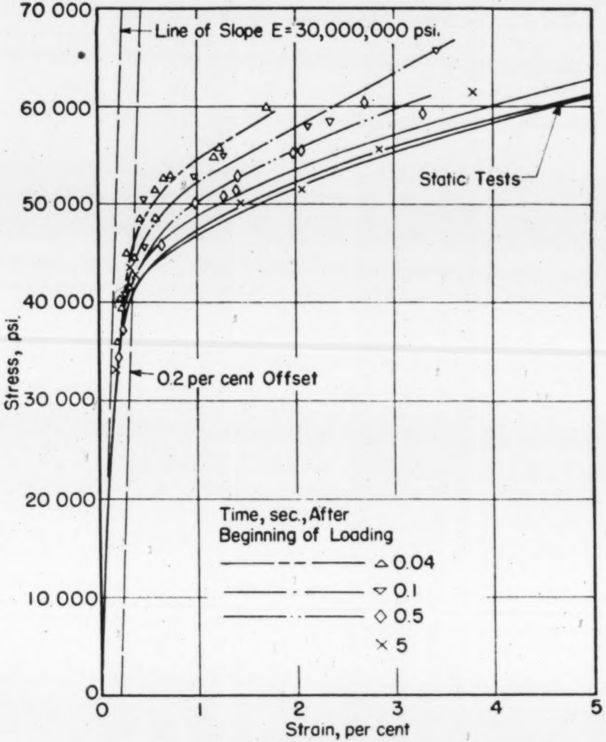


FIG. 18.—Stress *versus* Strain at Several Times After Beginning of Loading for Type 302 Stainless Steel

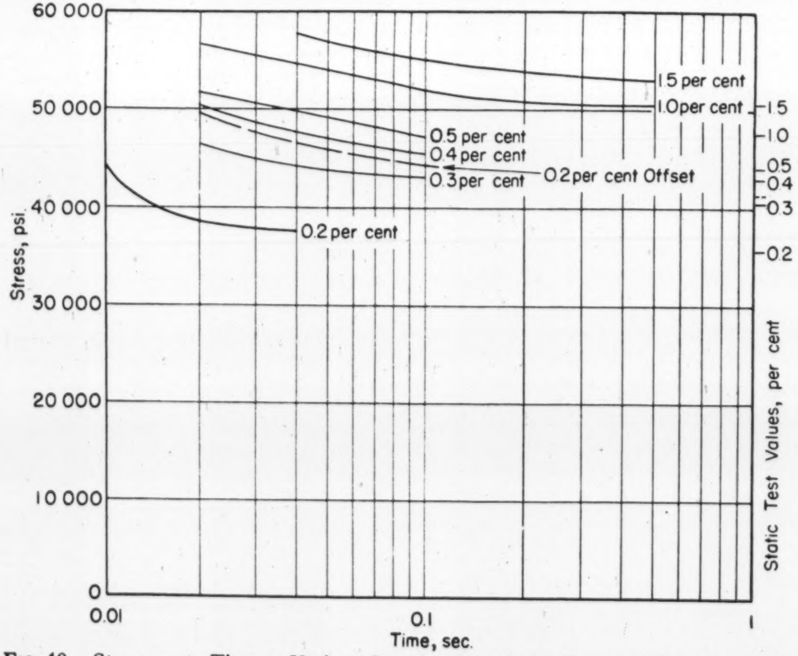


FIG. 19.—Stress *versus* Time at Various Constant Strains for Type 302 Stainless Steel.

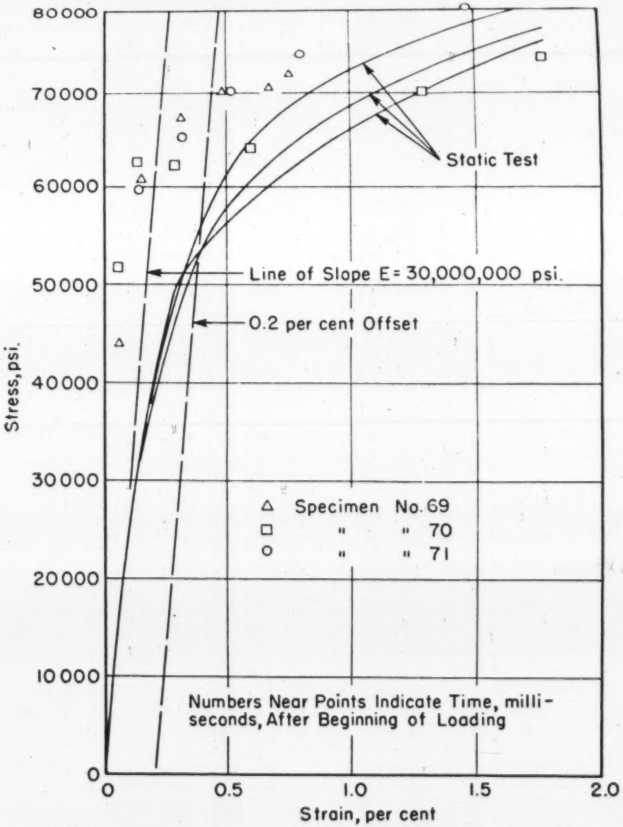


FIG. 20.—Stress *versus* Strain for three Rapid-Load Tests on S.A.E. 4130 Normalized Steel.

rate delays the attainment of the final load on the specimen. This is due to the same characteristic of the rapid-load machine which causes the drop in the load in tests on annealed low-carbon steel.

The stress-strain paths followed during three rapid-load tests on type 302 stainless steel are shown in Fig. 17. Static stress-strain curves are shown for comparison, and considerable increases in stress are noted in the rapid-load tests.

The records have been analyzed to indicate the stress *versus* strain relations at specific times after the beginning of loading. While the resulting curves are similar in character to those presented in Fig. 17, they should not be confused with the latter. The curves of Fig. 18 represent the stress *versus* strain obtained in the several tests for specific times after the beginning of loading. The points are obtained by determining from the experimental records the stress and corresponding corrected strain for the chosen time. A mean line was then drawn through the points. The stress and time corresponding to different values of strain can be determined from these curves. The results of such an analysis are presented in Fig. 19. The static test stresses corresponding to the selected strains are also indicated in the figure.

The results obtained on the normalized S.A.E. 4130 steel, the quenched-and-tempered S.A.E. 4130 steel, the 24S-T aluminum alloy; and the 75S-T aluminum alloy are similar to those obtained with the type 302 stainless steel. However, little or no increase of stress was observed under the rapid-load tests. The stress-strain paths followed by these materials in rapid-load tests are shown in Figs. 20, 21, 22, 23. The curves of stress *versus* time at various constant strains cannot be drawn for these materials as was done for the type 302 stainless steel since the stresses are not significantly different from the static values.

Tests have also been made in this laboratory on two mild steel ship plates. These materials have static stress-strain curves that exhibit definite yield points. The results of rapid-load tests on these materials are similar to those reported here for the 0.19 per cent carbon steel.

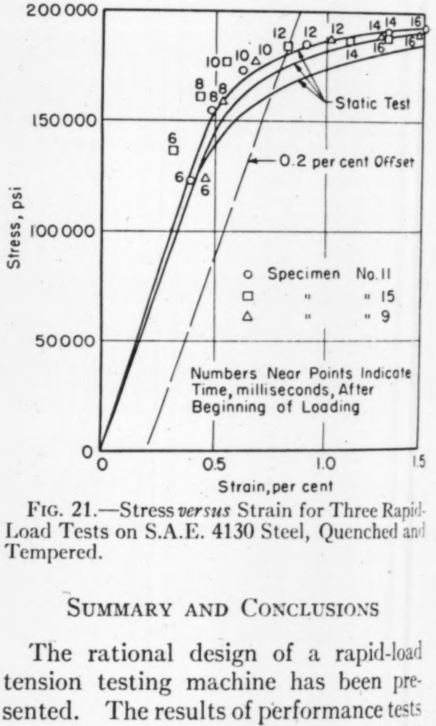


FIG. 21.—Stress *versus* Strain for Three Rapid-Load Tests on S.A.E. 4130 Steel, Quenched and Tempered.

SUMMARY AND CONCLUSIONS

The rational design of a rapid-load tension testing machine has been presented. The results of performance tests show that a tensile load may be applied to a specimen with this machine within a minimum time of about 5 millisec. without overshooting and oscillation of load.

Tests made with this machine on an annealed low-carbon steel show that a definite time is required for the initiation of plastic deformation when stresses above the yield point are applied. The time to initiate plastic strain in this material has been found to vary from 5 millisec. at a stress of about 51,000 psi. to 6

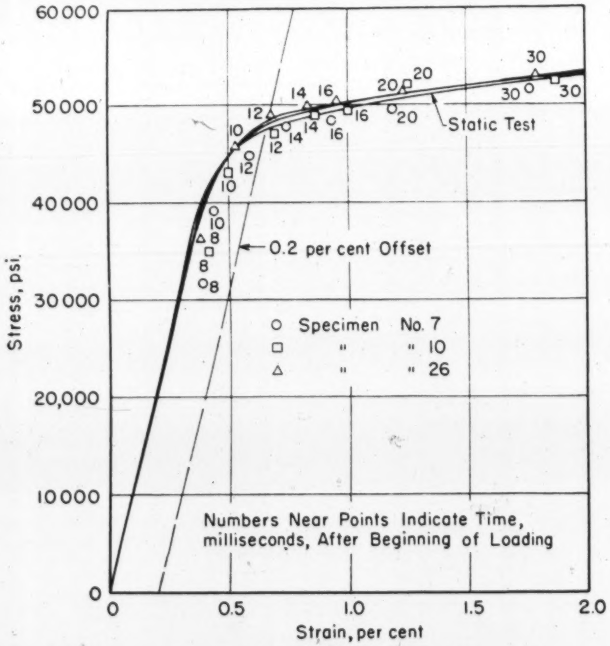


FIG. 22.—Stress *versus* Strain for Three Rapid-Load Tests on 24S-T Aluminum Alloy.

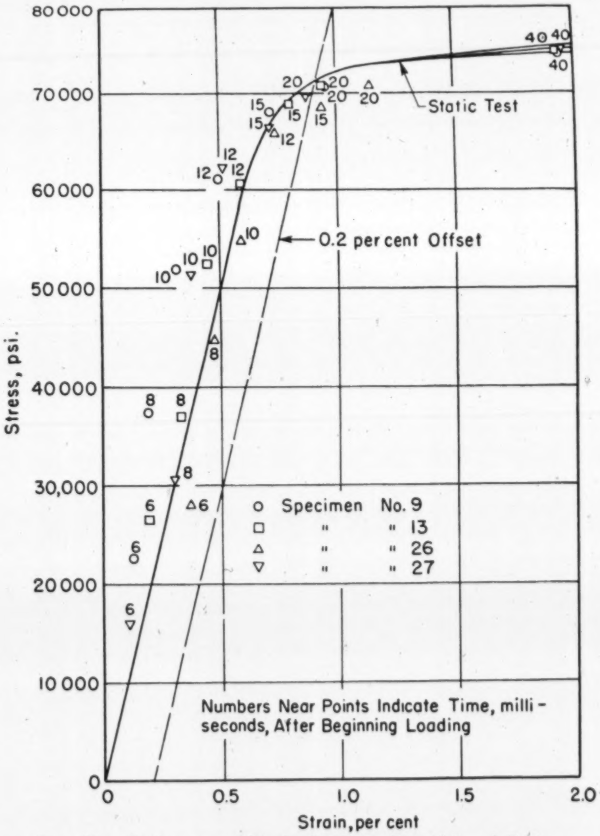


FIG. 23.—Stress *versus* Strain for Four Rapid-Load Tests on 75S-T Aluminum Alloy.

sec. at a stress of about 37,000 psi. The static lower yield stress of the material was 31,000 psi. Indirect evidence, supported by the results of other investigations, is presented to show that the initial plastic deformation is propagated through the gage length by one or more yield strain fronts. This propagation of the yield strain takes place while the stress is nearly constant throughout the gage length of the specimen and constant in time.

Tests made on five other materials, for which the static stress-strain diagram does not exhibit a yield point, have shown that plastic deformation occurred during the loading period and that no distinct delay time exists in such materials. Some evidence exists to show that materials of this type require a longer time at load to produce a given amount of plastic strain when the load is applied rapidly to values above the static elastic limit than when applied statically. However, in four of these materials this effect was negligible.

From these results it is evident that a definite time delay in the initiation of plastic deformation is associated only with materials from which the static stress-strain curve exhibits a definite yield point. The results presented in this paper may be of some assistance in explaining the anomolous behavior of mild steel subjected to longitudinal impact which has been reported by Duwez and Clark (**16**) and recently discussed by White (**19**).

Acknowledgment:

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DISCUSSION

Mr. M. J. Manjoine.[1]—This paper deals with the rate of application of a load on a material which has a definite yield point. Those who have seen mild steel yielding know that this yielding is quite a complicated mechanism of flow. This paper describes the averages of the stress, strain, and rate of strain which occur before, on initiation of, and during yielding.

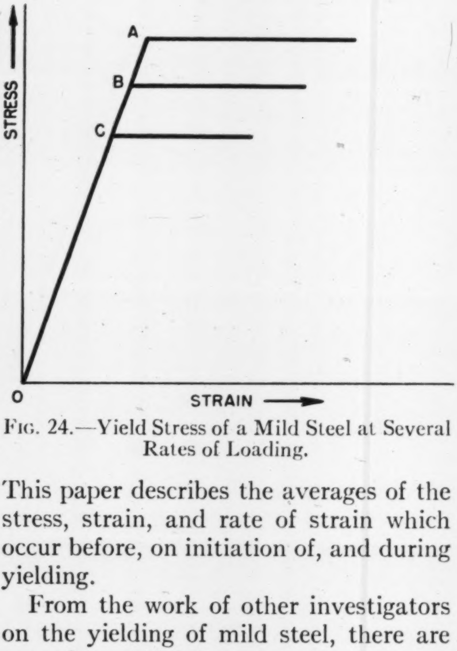

Fig. 24.—Yield Stress of a Mild Steel at Several Rates of Loading.

From the work of other investigators on the yielding of mild steel, there are some facts which have been brought out and checked. These facts are discussed in the paper and four of them can be summarized as follows:

1. The yield stress is a function of the rate of loading. This has been pointed out by Davis in reference (3) of this paper. Davis loaded the specimen by means of a weight traveling on a lever arm so that the load on the specimen could not drop at the yield point. Thus the loading of the specimen is similar to that employed by the authors of this paper.

2. The number of regions of yielding and the yield point strain increases with stress. In other words, as the rate of loading is increased and a higher yield stress is obtained, then a greater number of points of plastic flow are produced. These points unite into plastic zones which propagate through the entire working length. This fact is pointed out in references **1**, **2**, **3**, and **5** of the paper.

3. The rate of plastic flow, once yielding has been initiated, is a function of the stress. This has been shown by the writer[2] and by others as mentioned in the paper.

4. The drop of the load at the upper yield points indicates that an instability exists at this point and that initial plastic flow sets up stress concentrations which allow additional plastic flow at a lower external load. This presumes that the average strain rate is not increased.

In the light of these points, let us analyze how the material will yield under a loading cycle similar to that described in the paper. The yield stress of a mild steel at several rates of loading is shown in the accompanying Fig. 24.

When the specimen is loaded to point *B* above the static yield stress, *C*, at a rate which will cause yielding at point

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[2] M. J. Manjoine, "Influence on Rate of Strain and Temperature on Yield Stresses of Mild Steel," *Journal of Applied Mechanics*, Am. Soc. Mechanical Engrs., Vol. 11, pp. A-211-218 (1944).

A, then there are some imperfections or stress raisers randomly located in the material at which the stress will be equal to that at point *A*. Submicroscopic slip begins at these planes and stress raisers are generated at the boundaries of these active slip planes, so that the yielding will propagate slowly until these slip planes unite into a band or zone. The strain accompanying the submicroscopic slip is too small to be measured by the usual extensometer, but their effect can be detected by the electron microscopic and electron diffraction methods.[3] Only when these bands or zones are formed is there a sufficiently large strain to be detected on the surface. The plastic zone will propagate in accordance to the points 2, 3, and 4. Thus the time delay recorded by the authors is the time necessary for the material to form a plastic zone by some process similar to the one described above. The higher the point *B* with respect to point *A* in Fig. 24, the greater will be the number of regions which will begin to yield and the shorter will be the time necessary to form the plastic zone.

The authors are to be congratulated in presenting their data on the time delay for the initiation of the plastic zones, since this offers another opportunity to study the phenomena taking place in the yielding of mild steel. The above remarks are presented to point out that although there is a time delay for an external indication of plastic flow, the material is probably being deformed at submicroscopic points according to that predicted by the theory.

MESSRS. D. S. CLARK AND D. S. WOOD (*authors' closure*).—The authors are grateful to Mr. Manjoine for bringing out the important observation that submicroscopic slip must take place during the time delay for the initiation of macroscopic yielding in mild steel. In fact the strain accompanying the submicroscopic slip may be detected on many of the strain-time records. This is shown by the small slope of the record during the delay time, as can be seen on record No. 33 given in Fig. 11 of the paper. However, the sensitivity and accuracy of the strain determination is insufficient to permit quantitative determination of these small strains.

The exact mechanism of the submicroscopic slip, mentioned by Mr. Manjoine, and the manner in which it develops into the catastrophic yielding observed in mild steel have not been completely established as yet. The technique of testing described in this paper may provide additional means for further experimental study of these interesting questions.

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ELASTIC AND FRACTURE TOUGHNESS STUDIES OF A STAINLESS STEEL*

By Carl W. Muhlenbruch[1]

Synopsis

Type 301 stainless steel sheet and rod of several tempers is shown to have great elastic and fracture toughness, the former being defined as the area under the stress-strain diagram at the yield strength and the latter as the area under the true stress-true strain diagram to the ultimate load. The theoretical fracture toughness thus determined is compared with actual values obtained from tension impact tests. It is shown that the elastic toughness of type 301 stainless steel is equal to that of high-strength aluminum alloy on a weight-ratio basis and is much higher than that of S.A.E. 1020 or S.A.E. 2315 steel. The theoretical fracture toughness of annealed stainless steel is about three times that of 24S-T aluminum on a weight-ratio basis and three times that of S.A.E. 1020 or 2315 steel. The fracture toughness of these materials as obtained from true stress-true strain diagrams is found to agree within 14 per cent with values determined from tension impact tests. The significance of both elastic and fracture toughness is discussed.

The ability of an engineering material to resist shock loading is of particular importance in the design of aircraft, railway equipment, and trailer truck bodies. Recent extensive applications of stainless steel to parts thus loaded has led to the need of quantitative energy absorbing values for this material. The work described in this paper is intended to provide such data for type 301 stainless steel.

It has been shown by Mann[2] that the static stress-strain relationship can be correlated with impact data. This author indicates that the energy required to fracture a material suddenly in tension can be found as the area under a "potential" curve, based on true stress but conventional strain. The area under the conventional stress-strain diagram is taken as the external energy, dQ, and the area between this diagram and the true stress-conventional strain diagram is taken as the internal energy, dP_k. The sum of these two is the area under the true stress-conventional strain diagram and is shown to correlate almost perfectly with actual tension impact data.

Mann also gives the effect of velocity of stress for four different materials and shows that there is practically no change in the energy required to fracture a tension impact specimen when the velocity of the pendulum exceeds 10 ft. per sec., well within the velocity of 18.1 ft.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] Associate Professor of Civil Engineering, Northwestern Technological Inst., Evanston, Ill.

[2] H. C. Mann, "The Relation Between the Tension Static and Dynamic Tests," *Proceedings*, Am. Soc. Testing Mats., Vol. 35, Part II, pp. 323–340 (1935).

per sec. in these tests. It is also pointed out that the amount of energy in foot pounds per cubic inch varies with the size of specimen. The data indicate that when the length of the reduced portion of the specimen is two or more times the diameter, the effect of specimen size is not important. In this case the energy absorbed per cubic inch does not vary although the total energy increases with increased specimen size.

Farren and Taylor[3] have shown that the energy expended as heat in stretching a metal may be as much as 90 or 95 per cent of the total. Mann, however, states that the total energy effects, including thermal, are practically the same under both static and dynamic loading. Therefore it is not necessary to correct for thermal energy when correlating static and impact data. Duwez and Clark[4] as well as Hoppmann[5] point out that if a "critical velocity" is exceeded in tension impact, low energy absorption is observed.

This paper is not a discourse on the correlation of theoretical fracture energy from the static tension test with tension impact data. No attempt is made to track down every last remnant of energy, theoretical or experimental. An attempt is made, however, to provide quantitative toughness data, verified within limits with actual impact tests, and to show the structural importance of the toughness concept.

SIGNIFICANCE OF ELASTIC AND FRACTURE TOUGHNESS

The energy absorbing characteristics of a material are determined in textbooks on the strength of materials[6] from the modulus of resilience. The *term* is defined as that elastic energy which can be recovered upon release of any stress, whether in the elastic or the plastic range.

Quantitative values for resilience are commonly obtained by determining the area under the stress-strain diagram at the stress in question. The product of stress and strain is energy, the units for which are inch-pounds per cubic inch. The in-lb. is a measure of energy, and the cu. in. is a measure of volume; therefore, the term resilience indicates the amount of energy which 1 cu. in. of the material can absorb. It is interesting to note that the modulus of resilience at the proportional limit for structural steel has an average value of 15 in-lb. per cu. in. Physically this means that a weight of 1 lb. dropped through 15 in. onto a 1-in. cube would momentarily stress the material to 30,000 psi. By way of contrast, a static load of 30,000 lb. is necessary to set up the same stress in the cube.

In order to compare the energy absorbing characteristics in both the elastic and the plastic ranges, the term "toughness" will be used in this report. The modulus of resilience at the yield strength will therefore be redefined as the *elastic toughness* of the material, and the *total amount of energy* required to rupture a specimen will be termed the *fracture toughness*. This paper is not an attempt to show whether toughness can or cannot be obtained from the conventional stress-strain diagram. The author is of the opinion that better correlation of actual and theoretical fracture energy is obtained when the true stress-true strain diagram is used. The true unit stress is determined from the applied load and the actual cross-sectional area at that load, while the true unit strain is commonly determined from the relationship.[7]

$$\text{True strain} = \log A_o/A$$

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[3] W. S. Farren and G. I. Taylor, "The Heat Developed During Plastic Extension of Metals," *Proceedings*, Royal Soc. (London), Vol. 107, p. 423 (1925).

[4] P. E. Duwez and D. S. Clark, "An Experimental Study of the Propagation of Plastic Deformation Under Conditions of Longitudinal Impact," *Proceedings*, Am. Soc. Testing Mats., Vol. 47, p. 502 (1947).

[5] W. H. Hoppmann, "The Velocity Aspect of Tension-Impact Testing," *Proceedings*, Am. Soc. Testing Mats., Vol. 47, p. 533 (1947).

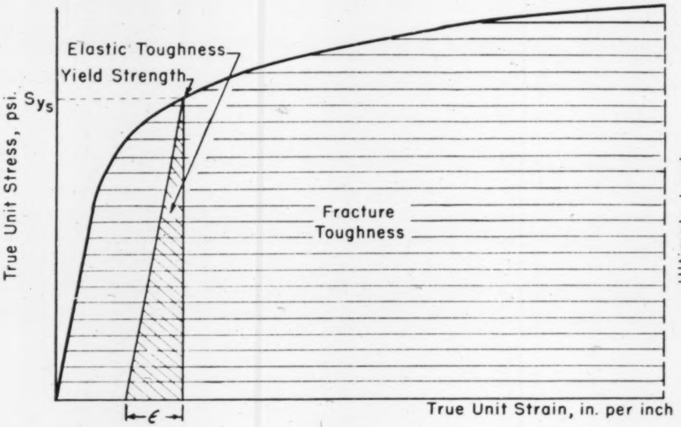
[6] P. G. Laurson and W. J. Cox, "Mechanics of Materials," John Wiley & Sons, Inc., p. 291, (1947).

[7] C. W. MacGregor, "The Tension Test," *Proceedings*, Am. Soc. Testing Mats., Vol. 40, p. 508 (1940).

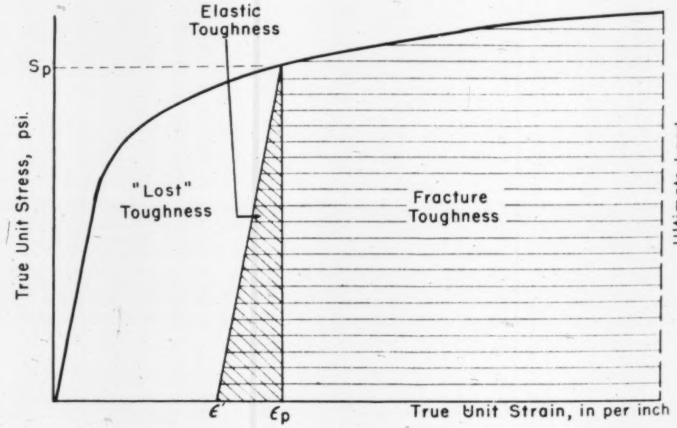
where:

A_o = original cross-sectional area in square inches, and

A = cross-sectional area at load at which true strain is to be determined, in square inches.



(*a*) Elastic Toughness as the Area under the True Stress - True Strain Diagram at the Yield Strength. Original Fracture Toughness, Prior to Stressing S_{ys}, is Shown by Horizontal Lines.



(*b*) Cold-Working Increases Elastic Toughness and Decreases Fracture Toughness.

FIG. 1.—Elastic and Fracture Toughness.

Figures 1 (*a*) and (*b*) show how the elastic and fracture toughness may be obtained from the true stress-true strain diagrams. The elastic toughness at the yield strength is taken as the area under the stress-strain diagram at the stress, s_{ys}. This triangular area will be $\frac{1}{2}\ s_{ys}\cdot\epsilon$. From the fundamental stress-strain relationship $E = s/\epsilon$, this area may therefore be written $(s_{ys})^2/2E$. The fracture toughness for the specimen is the total area under the entire stress-strain relationship as shown by the horizontal lines in Fig. 1 (*a*). As the material is stressed into the plastic range to the stress s_r, with the corresponding strain ϵ_p, some fracture toughness is lost. Release of the stress s_r allows the material to spring back and results in the permanent set ϵ'. The "lost" toughness is then the area under the stress-strain diagram which is not cross-hatched in Fig. 1(*b*). It may be noted from the figure that the elastic toughness has been increased and the fracture toughness remaining has been decreased. Cold-working will therefore increase elastic toughness but decrease fracture toughness.

TABLE I.—DESCRIPTION OF TEST SPECIMENS.

Specimen Designation	Material	Nominal Tensile Strength, psi.	Production Method	Relation to Rolling Direction	Form
16-A, B.........	Type 301 stainless	160 000	Cold-rolled, 18.1 per cent reduction	Parallel	Sheet
16-D, E.........	Type 301 stainless	160 000	Cold-rolled, 18.1 per cent reduction	Perpendicular	Sheet
18-A, B.........	Type 301 stainless	180 000	Cold-rolled, 30.5 per cent reduction	Parallel	Sheet
18-D, E.........	Type 301 stainless	180 000	Cold-rolled, 30.5 per cent reduction	Perpendicular	Sheet
20-A, B.........	Type 301 stainless	200 000	Taken from full-hard production material rolled to desired tensile strength	Parallel	Sheet
20-D, E.........	Type 301 stainless	200 000	Taken from full-hard production material rolled to desired tensile strength	Perpendicular	Sheet
HR-1 to 6.......	Type 301 stainless	200 000	$\frac{21}{32}$-in. diameter bar fully annealed, pickled, cold-drawn to $\frac{7}{16}$-in. diameter	Parallel	Rod
AR-1 to 6.......	Type 301 stainless	100 000	Same as HR series but annealed after drawing to $\frac{7}{16}$-in. diameter	Parallel	Rod
24-1 to 6.........	24S-T aluminum	68 000[a]	A high-strength aluminum alloy	Parallel	Rod
CS-1 to 6.......	S.A.E. 1020 steel	60 000[b]	Plain carbon steel	Parallel	Rod
23-1 to 6.........	S.A.E. 2315 steel	110 000	Hot-rolled 3.5 per cent nickel steel	Parallel	Rod

[a] Manufacturers "typical" value.
[b] Average value from A.S.T.M. Specification A 141.

GENERAL STRUCTURAL REQUIREMENTS FOR MATERIALS FOR ENERGY LOADINGS

The previous analysis for axial energy loads indicates that the energy absorbing capacity of a material or a structural component varies directly as the square of the applied stress and inversely as the modulus of elasticity. It follows that a material with a high modulus of elasticity must have a high yield strength if it is to possess good energy absorbing characteristics.

A comparison of materials, particularly for aircraft, will inevitably lead to a "strength-weight" ratio or "stiffness-weight" ratio. In this report the elastic and fracture toughness properties will also be compared on a weight-ratio basis. Based on the average weights of type 301 stainless steel and structural aluminum the weight ratio is 2.84.

In addition to high elastic toughness, materials used for energy loads must have a reserve of fracture toughness. It is possible to cold work a material to such an extent that the lost toughness occasioned by cold working is so great that the remaining fracture toughness is quite small. In this case the material may act elastically throughout most of its loading range but will have a very small plastic range, thus exhibiting the characteristics of a brittle material. Obviously in structures and aircraft it is desirable to have high elastic toughness plus enough fracture toughness that a proper reserve is maintained to take energy loads greater than those anticipated in design. In such cases, if the elastic toughness is exceeded, permanent set will result, but rupture will not occur. Without a reserve of fracture toughness, however, the material will fail when the elastic toughness is exceeded only slightly.

The combination of high fracture toughness and good ductility offers a distinct advantage for structural materials. Such a material can yield plastically at localized points of stress concentration and thus relieve the damaging effects of such a condition. The desirability of fabricating riveted or welded structures from ductile materials has long been recognized. Brittle materials on the other hand cannot yield locally to adjust themselves to loading conditions and so they must fracture.

It should be pointed out that the concepts presented in the previous energy considerations are also applicable to columns, beams, stiffened flat sheets, and other forms of structures.

Test Specimens and Method of Test

A complete description of all test specimens is given in Table I. All of the stainless steel sheet specimens except the 16 series were cut from 0.060-in. thick sheet material. The 16 series specimens were 0.120 in. thick. The stainless steel rod specimen stock was made as indicated in Table I. The aluminum specimens were turned from 0.75-in. rod and the other steel specimens from 0.875-in. rod.

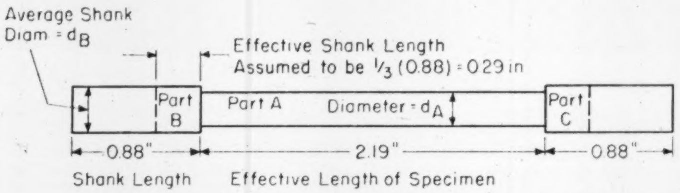


Fig. 2.—Determination of Percentage of Energy Absorbed by Shanks.

All sheet and rod specimens for tension testing were made in conformity with Standard Methods of Tension Testing of Metallic Materials (E 8 - 46).[8] Punch marks for sheet specimens were placed along the edge of the specimen rather than on the flat face.

Tension impact specimens were made in conformity, in so far as possible, with type V suggested by Tentative Methods of Impact Testing of Metallic Materials (E 23 - 47 T).[9] Because of its greater fracture toughness, the annealed stainless steel tension impact specimens were made smaller than those for the other materials. Every caution was taken to see that the completed specimens were free of internal stresses due to improper machining. A final polishing with crocus paper in the direction of testing further assured a stress-free specimen.

In order to provide a fast and highly accurate method of testing static specimens, Baldwin SR-4 electric strain gages were used to measure strain. These gages offered the opportunity of making almost simultaneous strain readings on both sides of the specimen so that it was possible to obtain satisfactory average strain readings into part of the plastic range. The gages were applied to the surface of the specimen in the approved manner. It was found that the gages would remain fastened to the surface of the stainless steel although the strains were far into the plastic range of the material.

Static tests were carried out in a Baldwin-Southwark hydraulic testing machine of 60,000-lb. capacity set up for 24,000-lb. maximum load (least reading 20 lb.). Specimens were placed in the jaws of the testing machine and loaded to an initial stress of 10,000 psi. All readings for strain were taken with reference to this initial load and were corrected to zero before plotting the stress-strain relationships. Load was applied so that the unit stress increments were 10,000 psi. Between readings, load was applied at a rate of approximately 1000 lb. per min.

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[8] 1946 Book of A.S.T.M. Standards, Part I-A, pp. 698–709.

[9] 1947 Supplement to Book of A.S.T.M. Standards, Part I-A, p. 381.

When a specimen exhibited a lack of elastic action, the cross-sectional area was measured at each load. It was thus possible to obtain both conventional stress-strain data as well as the true stress-true strain data. The reduced dimensions of the cross-section of sheet specimens were obtained rapidly with two micrometers and two observers. Every effort was made to obtain the actual cross-sectional area at the true ultimate load. This was difficult to do, however, since the specimen was changing rapidly at this point. The error in either dimension at the ultimate is not considered to be more than 5 per cent in any case and less than this as an average. Because of this it is quite likely that the true unit stress at the ultimate load for the sheet specimens may not be correct. An error of 5 per cent in one dimension of a sheet specimen will cause a greater error in the fracture energy due to the error which is also introduced in the true strain. If the error in both dimensions of a sheet specimen is accumulative the fracture toughness will be in even greater error.

TABLE II.—TENSION IMPACT TEST DATA.

Specimen Number	Material	Diameter, in.	Volume, in.	Corrected Volume, cu. in.	Impact Value, ft-lb.	Actual Fracture Toughness, in-lb. per cu. in.	Average Theoretical Fracture Toughness, in-lb. per cu. in.
HR-2	Hardened stainless rod	0.2354	0.0953	0.0993	98.5	11 900	
HR-4		0.2350	0.0951	0.0991	101.0	12 220	
HR-5		0.2352	0.0951	0.0991	106.2	12 870	
HR-6		0.2338	0.0944	0.0984	105.8	12 900	
Avg.	....	....	....	....	102.9	12 470	14 470[a]
AR-1	Annealed stainless rod	0.1691	0.0492	0.0516	216.1	50 300	
AR-3		0.1702	0.0499	0.0523	215.6	49 500	
AR-4		0.1700	0.0497	0.0521	208.0	48 000	
AR-5		0.1694	0.0494	0.0518	209.1	48 500	
Avg.	....	....	....	....	212.2	49 080	56 100[a]
24-4	24S-T aluminum rod	0.2505	0.0966	0.1016	58.0	6 850	
24-5		0.2501	0.0965	0.1013	55.8	6 600	
24-6		0.2502	0.0965	0.1013	57.4	6 790	
Avg.	....	....	....	....	57.1	6 750	7 060[b]
CS-4	S.A.E. 1020 steel rod	0.2498	0.0960	0.1008	180.0	21 400	
CS-5		0.2506	0.0968	0.1017	161.9	19 100	
CS-6		0.2495	0.0958	0.1006	182.7	21 800	
Avg.	....	....	....	....	174.9	20 770	19 100[b]
23-4	S.A.E. 2315 steel rod	0.2503	0.0966	0.1016	173.5	20 500	
23-5		0.2501	0.0965	0.1013	190.1	22 500	
23-6		0.2492	0.0957	0.1005	192.0	22 900	
Avg.	....	....	....	....	185.2	21 970	21 700[b]

[a] Average of 2 specimens from Table IV.
[b] Average of 3 specimens from Table IV.

A Riehle combination impact testing machine was used in the 220-ft-lb. range for the tension impact tests. The striking velocity for this range is 18.1 ft. per sec., well within the "critical velocity" and greater than the 10 ft. per sec. min. suggested by Mann.

Since the tension impact specimens varied considerably in diameter and slightly in length, it was necessary to make a correction in each case for the energy absorbed by the reduced portion

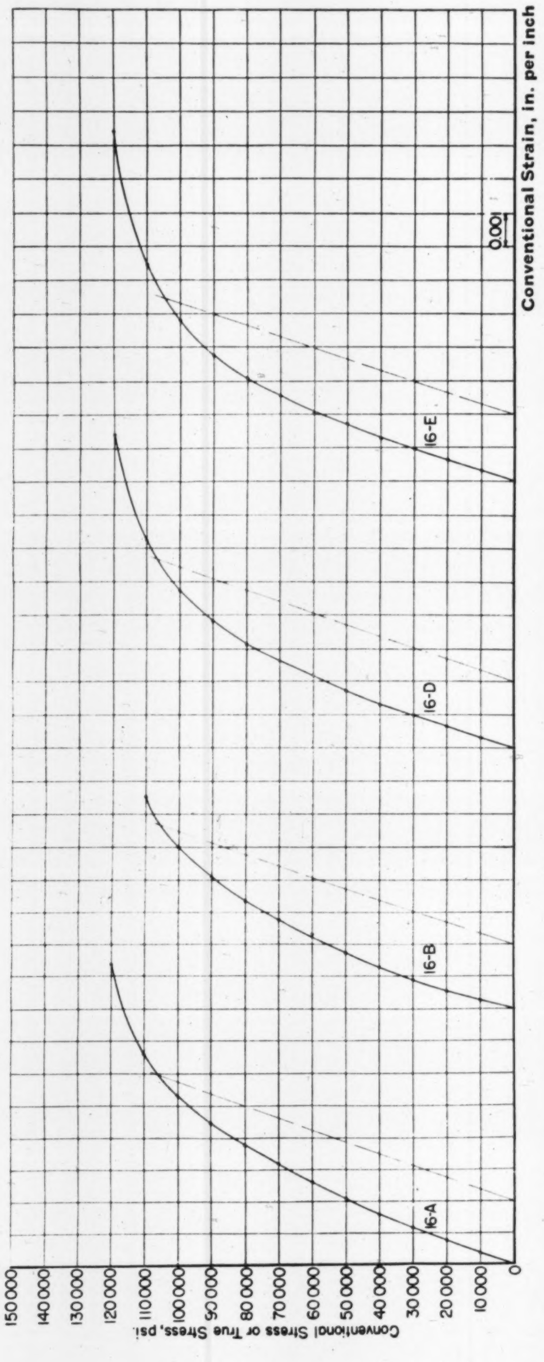

FIG. 3.—"Elastic" Range Stress-Strain Diagrams for Type 301 Cold-Rolled Stainless Steel Sheet, Reduced 18.1 per cent to 160,000 psi. Tensile Strength.

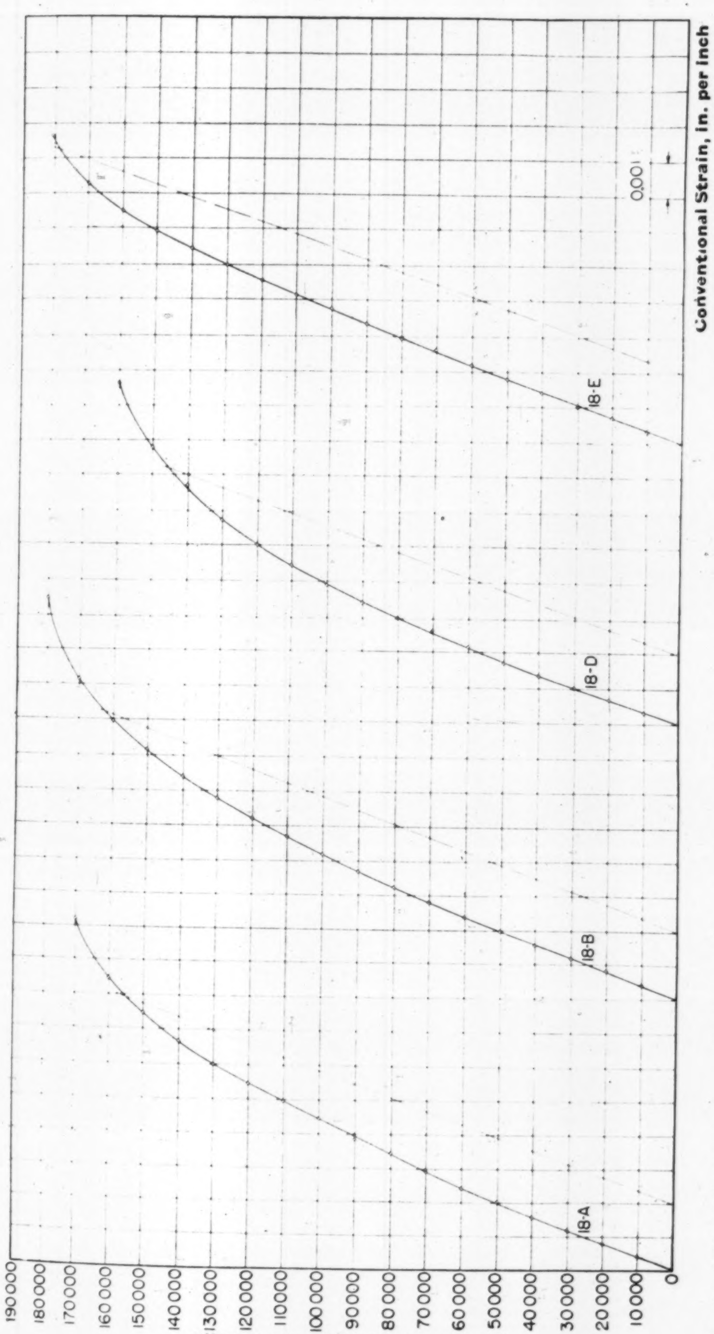

FIG. 4.—"Elastic" Range Stress-Strain Diagrams for Type 301 Cold-Rolled Stainless Steel Sheet, Reduced 30.5 per cent to 180,000 psi. Tensile Strength.

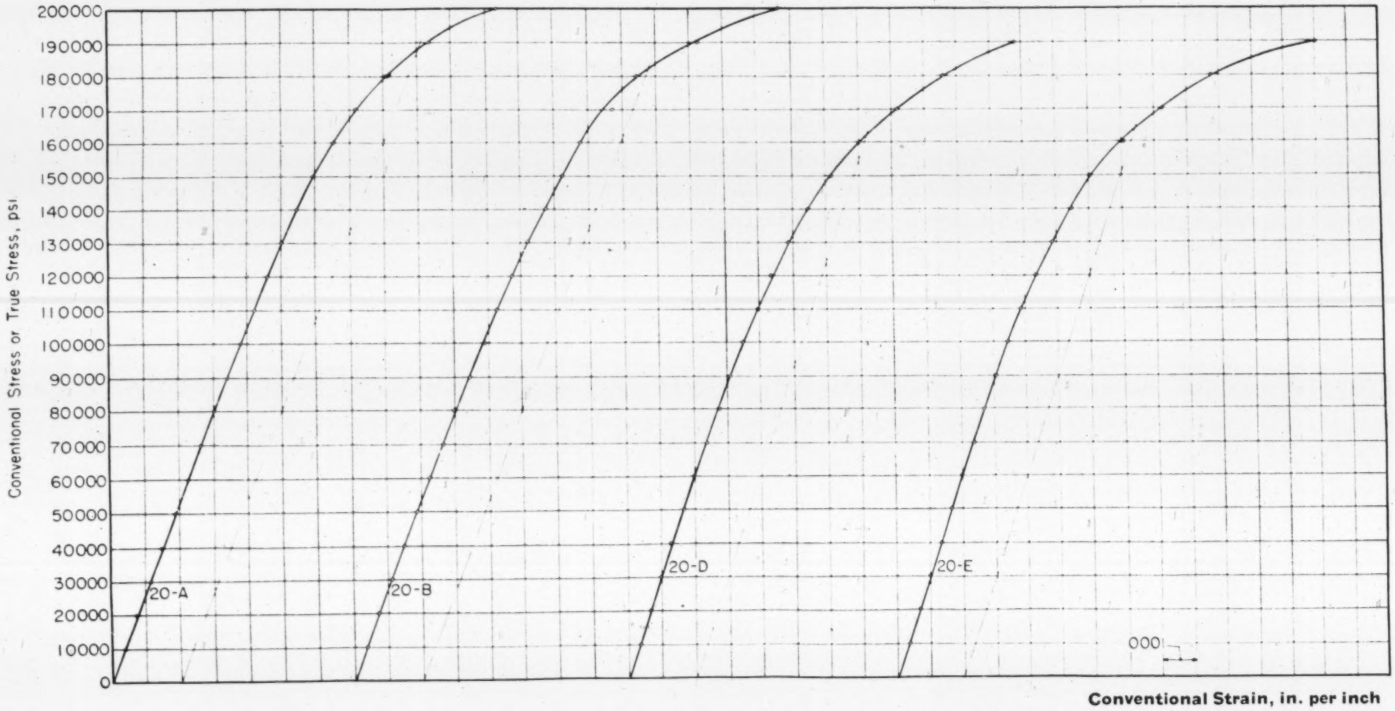

FIG. 5.—"Elastic" Range Stress-Strain Diagrams for Type 301 Cold-Rolled Stainless Steel Sheet, Rolled Full-Hard to 200,000 psi. Tensile Strength.

of the specimen or by the shank. This was done on the basis of the resilience capacity of each portion of the specimen. The length of the reduced portion was considered to be the actual length plus one half the fillet radius at each end, as shown in Fig. 2. Based on the stress distribution characteristics in screw threads it was assumed that only one third of each shank length would be stressed and therefore absorb energy. The total fracture energy capacity of the specimen is the sum of the three portions shown in Fig. 2. When the stress in part A is s_A the stress in the shank, s_B, will be $d_A^2/d_B^2\ (s_A)$. Since $d_B = d_C$ the total energy absorbed at any stress in the elastic range will be

$$K = \frac{s_A^2}{2E}\left(\frac{d_A^2\pi}{4}\cdot 2.19\right) + 2\frac{s_B^2}{2E}\left(\frac{d_B^2\pi}{4}\cdot 0.29\right)$$

Substituting for s_B in terms of s_A and evaluating this expression for the specimen diameters given in Table II gives the following percentages of energy absorbed by the reduced portion:

Hardened stainless rod................	91.5
Annealed stainless rod................	95.3
24S-T aluminum, S.A.E. 1020 steel and S.A.E. 2315 steel..................	95.4

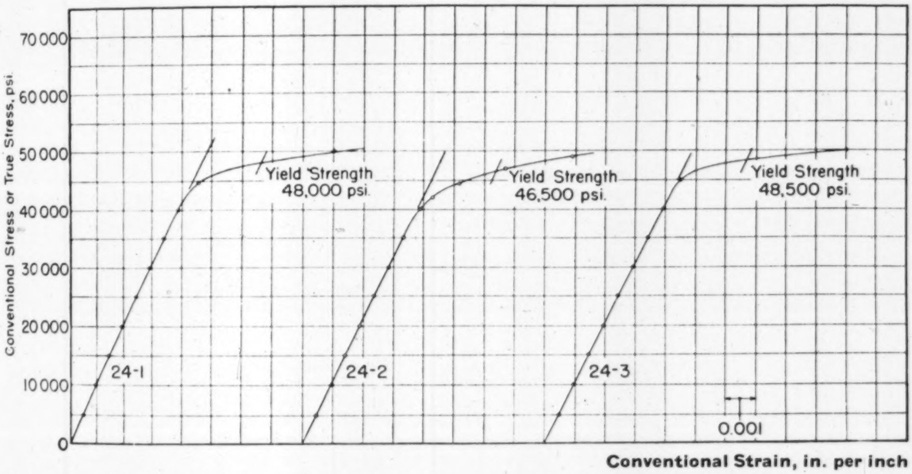

FIG. 6.—"Elastic" Range Stress-Strain Diagrams for 24S-T Aluminum Alloy Rod.

It was assumed that these correction factors could be applied to the fracture toughness as well as the resilience within the elastic range. The volume of the reduced portion of each specimen was accordingly increased by the amount of this error. The use of this corrected volume gives results the same as those that would be obtained by reducing the fracture toughness.

It has been assumed that the area under the true stress-true strain diagram at the ultimate load is a satisfactory measure of fracture toughness. The author[10] and others have shown that a ductile material stretches uniformly throughout its length up to the ultimate load. The diameter therefore changes uniformly also. Beyond this load one localized portion of the specimen reduces in area and eventually fractures. The small additional fracture energy stored in this volume cannot be applied to the larger volume since the latter is not continuing to reduce in diameter. The magnitude of this energy varies for materials of different ductilities and has been ignored in this paper.

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[10] C. W. Muhlenbruch, "Testing of Engineering Materials," D. Van Nostrand Co., p. 57 (1944).

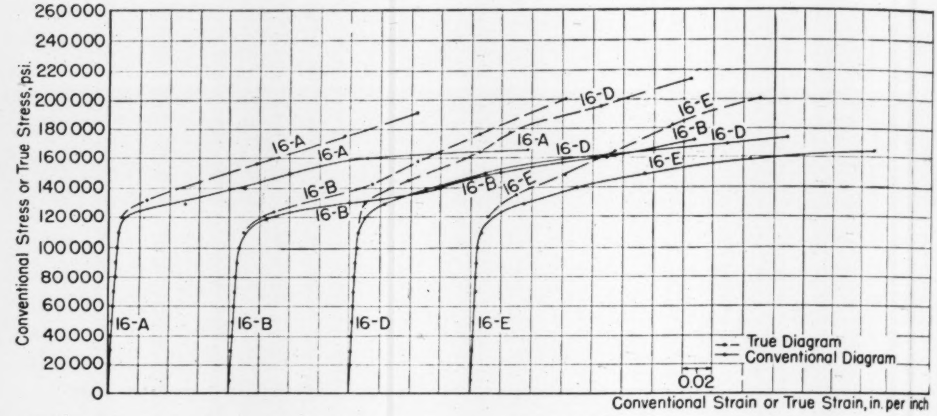

FIG. 7.—Complete Stress-Strain Diagrams for Type 301 Cold-Rolled Stainless Steel Sheet, Reduced 18.1 per cent to 160,000 psi. Tensile Strength.

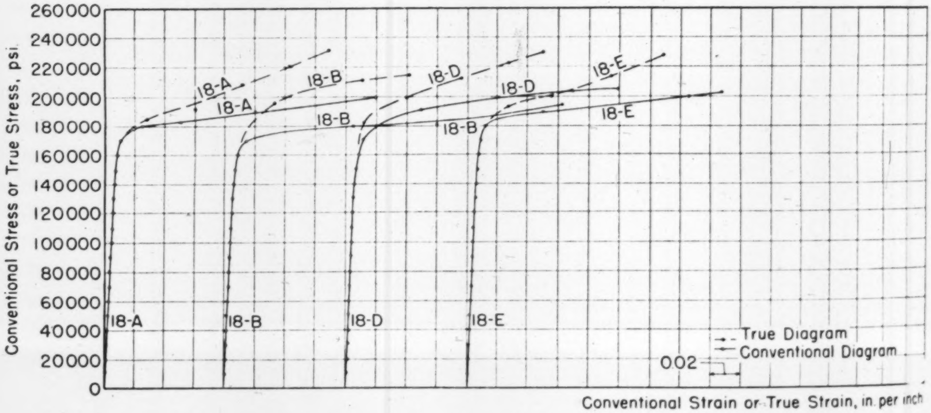

FIG. 8.—Complete Stress-Strain Diagrams for Type 301 Cold-Rolled Stainless Steel Sheet, Reduced 30.5 per cent to 180,000 psi. Tensile Strength.

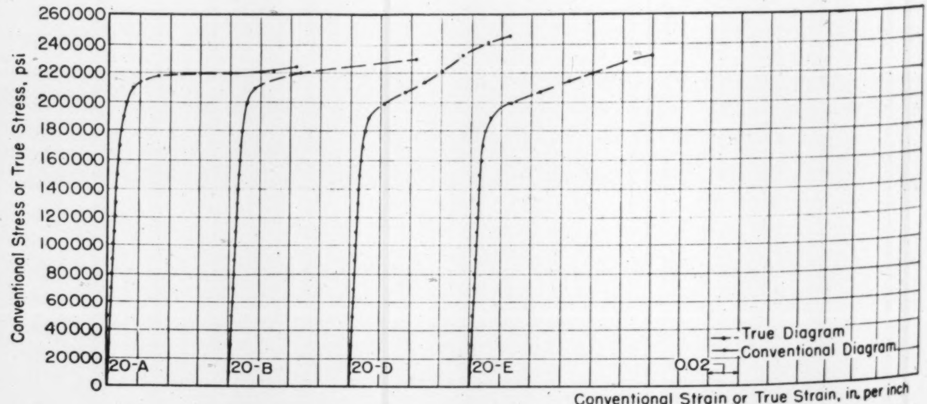

FIG. 9.—Complete Stress-Strain Diagrams for Type 301 Cold-Rolled Stainless Steel Sheet, Rolled Full-Hard to 200,000 psi. Tensile Strength.

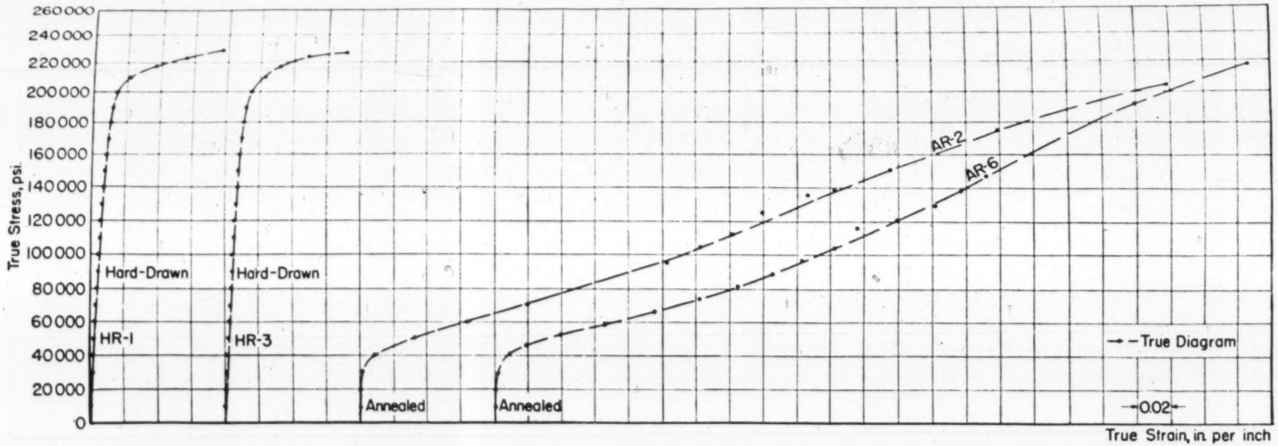

FIG. 10.—Complete Stress-Strain Diagrams for Type 301 Stainless Steel Rod Cold-Drawn from $\frac{21}{32}$ in. Diameter to $\frac{7}{16}$ in. Diameter.

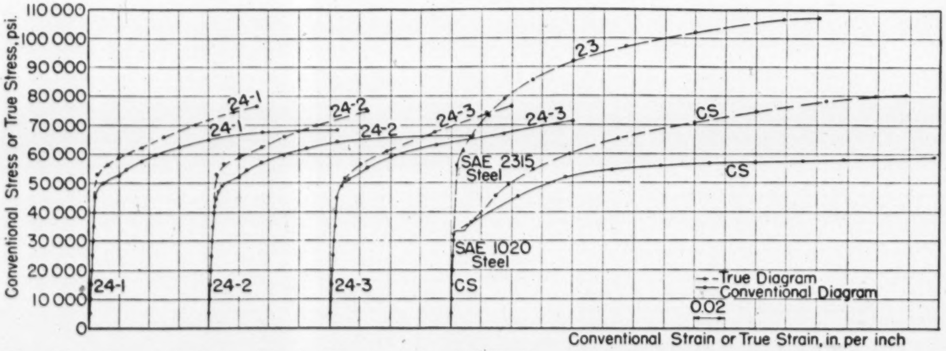

FIG. 11.—Complete Stress-Strain Diagrams for 24S-T Aluminum Alloy, S.A.E. 1020 Steel (Average of 3 Specimens), and S.A.E. 2315 Steel (Average of 3 Specimens).

RESULTS OF TESTS

TABLE III.—RESULTS OF STATIC TENSION TESTS.

Specimen	Yield Strength,[a] psi.	Tensile Strength, psi.	Modulus of Elasticity, psi.	Elongation,[b] per cent
16-A	106 000	162 800	26 600 000	30.0
16-B	105 500	166 000	28 800 000	37.0
Avg.	105 750	164 400	27 700 000[c]	33.5
16-D	107 000	173 000	28 400 000	33.5
16-E	104 500	168 800	29 700 000	30.5
Avg.	105 750	170 900	29 050 000[c]	32.0
18-A	155 500	200 000	25 600 000	21.5
18-B	162 700	196 800	25 600 000	28.5
Avg.	159 100	198 400	25 600 000[c]	25.0
18-D	145 200	205 000	28 300 000	20.0
18-E	178 800	204 000	28 400 000	18.0
Avg.	162 000	204 500	28 350 000[c]	19.0
20-A	188 000	213 000	26 600 000	16.5
20-B	182 400	210 000	26 600 000	18.0
Avg.	185 200	211 500	26 600 000[c]	17.3
20-D	162 600	223 000	30 000 000	18.5
20-E	164 000	220 000	29 800 000	16.0
Avg.	163 300	221 500	29 900 000[c]	17.3
HR-1	158 000	197 800	23 900 000	14.5
HR-3	148 000	197 400	25 200 000	14.0
Avg.	153 000	197 600	24 550 000[c]	14.3
AR-2	34 500	127 500	29 200 000	49.0
AR-6	35 100	136 800	28 900 000	50.5
Avg.	34 800	132 150	29 050 000[c]	49.8
24-1	48 000	68 500	10 420 000	16.5
24-2	46 500	68 100	10 530 000	15.0
24-3	48 300	69 200	10 310 000	15.4
Avg.	47 600	68 600	10 420 000	15.6
CS-1	33 500	58 200	30 150 000	34.8
CS-2	35 600	60 400	30 050 000	32.5
CS-3	31 300	58 100	29 550 000	35.0
Avg.	33 470	58 900	29 920 000	34.1
23-1	58 300	114 400	29 400 000	27.5
23-2	54 800	118 000	29 550 000	25.9
23-3	55 500	109 500	29 700 000	29.1
Avg.	56 200	113 970	29 550 000	27.5

[a] At 0.2 per cent permanent set for all materials but S.A.E. 1020 steel for which yield point is given.

[b] 2-in. gage length.

[c] The modulus of elasticity for the stainless steel is the initial value, based on the average slope of the first four plotted points.

Figures 3 through 6 give the tensile stress-strain diagrams in the "elastic" range for all of the materials except the stainless steel rod, S.A.E. 1020 steel, and S.A.E. 2315 steel. Complete stress-strain diagrams, conventional and true, are given in Figs. 7 through 11 for all series excdpt 20, HR, AR, and 23, for which only true relationships are given. Values for yield-strength, tensile strength, modulus of elasticity, and percentage elongation are given in Table III.

It is generally recognized that the speed of testing austenitic stainless steel has a pronounced effect on the shape of the initial portion of the stress-strain diagram. In general a very fast rate of testing yields a diagram that shows the stress-strain relationship to be non-linear almost from zero stress. A slow rate of testing modifies this tendency. Any interpretation of the data should recognize that these tests were made at a slow testing speed.

Considerable difficulty was encountered in measuring the reduced dimensions of the stainless steel sheet specimens. Although two micrometers and two observers were used, some time lag was inevitable between the two readings. In the plastic range near the ultimate load more tapering of the specimens was observed than for the round specimens. The relatively rapid change in dimensions of the fully cold-worked stainless steel specimens near the ultimate load also made reading difficult. It is felt that the true stress-true strain diagrams obtained for the sheet specimens give falsely high values for fracture energy. Because of this conviction it was decided to obtain the static tensile stress-strain diagrams for round specimens also. These specimens permitted data for true stress and true strain to be obtained with a minimum of difficulty.

A comparison of the initial portion of the stress-strain diagram for the stainless steel specimens and for the 24S-T aluminum alloy or any of the other steels shows one important difference. This is the characteristic tendency of the stainless steel to break very slowly from the initial straight-line relationship while the other materials exhibit a rapid transition from the elastic to the plastic range. All specimens other than annealed stainless steel, AR series, have this tendency. Throughout the tests it was observed that the higher strength materials had the least tendency to deviate from a straight-line relationship in the initial portion of the diagram.

TABLE IV.—ELASTIC AND FRACTURE TOUGHNESS AS OBTAINED FROM STATIC TENSILE STRESS-STRAIN DIAGRAMS.

Specimen	Material	Form	Elastic Toughness, in-lb. per cu. in.	Initial Fracture Toughness, in-lb. per cu. in.
16-A	Type 301 stainless	Sheet	211	35 300
16-B		Sheet	193	33 400
Avg.			202	34 350
16-D	Type 301 stainless	Sheet	201	37 200
16-E		Sheet	184	30 600
Avg.			193	33 900
18-A	Type 301 stainless	Sheet	472	30 100
18-B		Sheet	516	29 300
Avg.			494	29 700
18-D	Type 301 stainless	Sheet	365	27 100
18-E		Sheet	562	25 800
Avg.			464	26 450
20-A	Type 301 stainless	Sheet	645	25 500
20-B		Sheet	625	25 800
Avg.			635	25 650
20-D	Type 301 stainless	Sheet	441	22 100
20-E		Sheet	451	24 200
Avg.			446	23 150
HR-1	Type 301 stainless	Rod	523	15 020
HR-3		Rod	435	13 920
Avg.			479	14 470
AR-2	Type 301 stainless	Rod	20	58 100
AR-6		Rod	21	54 000
Avg.			21	56 050
24-1	24S-T aluminum	Rod	110	7 100
24-2		Rod	103	6 620
24-3		Rod	113	7 450
Avg.			109	7 060
CS-(Avg.)[b]	S.A.E. 1020 steel	Rod	19[a]	19 100
23-(Avg.)[b]	S.A.E. 2315 steel	Rod	53	21 700

[a] Based on yield point.
[b] Average of 3 specimens.

Elastic toughness values are reported in Table IV. These values have been calculated from the area under the stress-strain diagram at the yield-strength, using the relationship $(s_{ys})^2/2E$. The elastic toughness of the HR series, round specimens, agrees very well with those for the 18 series, sheet specimens. This would seem to indicate that all of the elastic toughness values for stainless steel are representative. Fracture toughness data are also given in Table IV. It is felt that the fracture toughness values for the sheet specimens, particularly the 18 and 20 series, are too high, due to the difficulty of measuring cross-sectional area as discussed previously. The fracture toughness of the round specimens is considered representative. The data shows that cold-working increased the elastic toughness of the stainless steel but decreased fracture toughness. Actual values are higher in both cases for specimens tested parallel to the direction of rolling than for perpendicular specimens. Specimens 20-A and B of fully cold-worked stainless steel had an elastic toughness 3.1 times that of specimens 16-A and B. By contrast the fracture toughness of the annealed AR round specimens is found to be 3.88 times that of the HR series (comparable to the 18 series in other properties). The elastic toughness of the full cold-worked 20 series is 5.83 times that of the 24S-T aluminum or about two times as much on a weight ratio basis. This value for the 18 series is 4.53, or 1.64 corrected for weight. The S.A.E. 1020 and 2315 steels are considerably lower in elastic toughness than any of the cold-worked stainless series. The value for 18-A and B is shown in Table IV to be 26 times that for S.A.E. 1020 steel and 9.3 times that for S.A.E. 2315 steel.

The stress-strain diagrams show that the elastic toughness of the stainless steel can be raised considerably by increasing the permanent set beyond the 0.2 per cent at the yield strength. This is not true for materials which pass rapidly from the elastic to the plastic range as does the 24S-T aluminum. It may be shown from Fig. 6 that if the aluminum is stressed to a permanent set of 0.3 per cent, for example—an increase in strain of 50 per cent—the increase in elastic toughness for specimen 24-1 is 3.6 per cent. From Fig. 4 for specimen 18-B, however, the increase in elastic toughness at 0.3 per cent permanent set is 14.1 per cent. The ratio of the elastic toughness values at 0.2 per cent permanent set for the two materials was shown above to be 1.64 when corrected for weight. At 0.3 per cent permanent set this ratio is 1.82 per cent, an increase of 9.9 per cent. None of the other steels tested possess this property of stainless steel. It would appear from the data that a stainless steel must have a yield strength of approximately 130,000 psi. if it is to be equal to 24S-T aluminum in elastic toughness on a weight ratio basis. Type 301 of $\frac{1}{4}$- hard grade would be the temper which would come the closest to satisfying this requirement.

It has been pointed out that structural parts subjected to energy loading should not only possess high elastic toughness but also high fracture toughness. It has been pointed out that a gain in one is made at the sacrifice of the other, as is shown by the data in Table IV. The contrast between elastic and fracture toughness capacities is apparent from Fig. 10. The theoretical fracture toughness of these specimens are given in Table IV as 14,470 in-lb. per cu. in. for the fully cold-worked material and 56,100 in-lb. per cu. in. for the annealed stainless steel. The other stainless steel specimens had fracture toughness values between these two extremes. It should be noted again that the values obtained for the stainless steel sheet specimens are not considered to be representative.

The most informative data on fracture toughness is that provided by the tension impact tests as given in Table II. It may be seen from this table that the actual and theoretical fracture toughness values are in good agreement except for the HR stainless steel series for which the theoretical value is 13.8 per cent in error and for the AN series for which the error is 12.5 per cent. The reason why the stainless steel is in greater error than the other materials is not apparent.

The data of Table II show that the theoretical fracture toughness of annealed stainless is 2.8 times that of 24S-T aluminum on a weight ratio basis, 2.94 times that of S.A.E. 1020 steel, and 2.71 times that of S.A.E. 2315 steel. On the basis of the actual fracture toughness these values become 2.56, 2.37, and 2.24 respectively. Comparing the HR stainless series and the 24S-T aluminum series for elastic and actual fracture toughness give weight corrected values of 1.53 and 0.65, indicating that the former is too high and the latter not high enough. Decreasing the elastic toughness will increase the fracture toughness. The trend of the data in Table IV indicates that for the hypothetical stainless steel which has a yield strength of 130,000 psi. and is therefore exactly equal to the 24S-T aluminum in weight corrected elastic toughness, the corrected fracture toughness (based on tension impact data) would be 1.36 times the aluminum. It follows therefore that the stainless steel would have a reserve of fracture toughness not possessed by the 24S-T aluminum.

A subject for additional study would be to determine the same properties for the same materials but at temperatures in excess of 300 and 400 F. Studies of stainless alloys other than type 301 and notched tension impact specimens would also prove profitable.

CONCLUSIONS

The data presented in this report and the theoretical considerations involved seem to warrant the following general conclusions for type 301 stainless steel:

1. A stainless steel with a yield strength of 130,000 psi. would have an elastic toughness equal to that of 24S-T aluminum on a weight ratio basis. Based on actual tension impact data, the fracture toughness of this hypothetical material would be 36 per cent more than that of the aluminum on a weight ratio basis.

2. Because its stress-strain diagram does not break rapidly from the elastic to the plastic range, the energy capacity of stainless steel continues to increase beyond the yield strength. The elastic toughness of stainless steel of 180,000 psi. nominal tensile strength can be increased 14.1 per cent when the permanent set is increased from 0.2 per cent to 0.3 per cent. The same conditions for 24S-T aluminum produce an increase of 3.6 per cent.

3. The elastic toughness of 180,000 psi. tensile strength stainless steel is 26 times that of S.A.E. 1020 steel, 9.3 times that of S.A.E. 2315 steel and 1.64 times that of 24S-T aluminum on a weight ratio basis.

4. The energy required to fracture a specimen as obtained from the tension impact test correlates within 14 per cent with the area under the true stress-true strain diagram.

5. The fracture toughness of annealed stainless steel, based on actual impact data, is 2.37 times that of S.A.E. 1020 steel, 2.24 times that of S.A.E. 2315 steel, and 2.56 times that of 24S-T aluminum corrected for weight. The theoretical toughness gives higher values.

Acknowledgment:

The author wishes to acknowledge the valuable assistance of W. B. Pierce, Manager, and R. A. Lincoln, staff member, of the Sales Development and Engineering Service Department of the Allegheny Ludlum Steel Corp. in carrying out this work and in providing all of the stainless steel test specimens.

DISCUSSION

Mr. Russell Franks.[1]—I am impressed with the elastic toughness and fracture toughness data presented in Mr. Muhlenbruch's paper.

The information given concerns primarily modulus of resilience and shows that even though the strength of the austenitic stainless steel is greatly increased by application of cold work, the resulting product still retains high capacity for energy absorption before fracture, which means that the steel has an excellent combination of strength and toughness. I should like to ask Mr. Muhlenbruch whether he has secured information from those who have used these stainless steels for structural components as to whether they have been able to confirm the high degree of elastic and fracture toughness possessed by the cold-rolled 18 per cent chromium, 8 per cent nickel steel.

I should also like to ask if he has done any work on notched tension impact tests or on standard tension impact tests at temperatures up to 400 F. or slightly higher. Information of this type would be of great value in building high-strength devices that operate under such temperature conditions. I should like to congratulate the author in bringing to our attention these important mechanical characteristics of the cold-rolled stainless steels.

Mr. C. W. Muhlenbruch (*author*).—Although no industry-wide survey of users of stainless steel structural components has been made, a few contacts have revealed in most cases that service records of the components themselves substantiate the contentions made by the author. It is hoped that additional performance data will be forthcoming.

Subsequent to submitting this paper a few notched tension-impact tests were made for the materials included in the original paper. No high-temperature tests have been made. Notched tension impact specimens conformed to type U suggested in A.S.T.M. Tentative Methods of Impact Testing of Metallic Materials (E 23 – 47 T).[2] The test results were as follows:

Specimen	Material	Impact Value, ft-lb.	Impact Value Corrected For Weight, ft-lb.[a]
HR-N1.....	Hardened stainless rod	20.5	
HR-N2.....		35.0	
Avg......		27.8	9.8
AR-N1.....	Annealed stainless rod	44.0	
AR-N2.....		48.0	
Avg......		46.0	16.2
24-N1......	24S-T aluminum rod	5.5	
24-N2......		5.0	
Avg......		5.3	...

[a] By dividing by the weight factor of 2.84.

Based on the weight-corrected impact strength, the fully hardened stainless steel rod is able to absorb 85 per cent more than the 24S-T aluminum alloy, while the annealed stainless rod is able to absorb 206 per cent more. It should be noted that these comparison values are considerably greater than the values reported in the paper for the unnotched tension impact specimens. This indicates that the notch sensitivity of the stainless steel is considerably less than that of the aluminum tested.

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[1] Manager, Development Dept., Electro Metallurgical Div., Union Carbide and Carbon Corp., Pittsburgh, Pa.

[2] 1947 Supplement to Book of A.S.T.M. Standards, Part I-A, p. 381.

MR. P. E. CAVANAGH.[3]—Is it possible that the differences in the measured and calculated fracture toughnesses might be due to differences in the effective energy-absorbing volumes of the impact samples in different metals with different energy transmitting characteristics.

And, secondly, has an attempt been made to calculate the effective volume of the notched specimens?

MR. MUHLENBRUCH (*author*).—There can be no doubt that some of the difference was due to variation in energy absorbing volumes as stated by Mr. Cavanagh. It is felt, however, that this factor does not account for all of the difference observed. No attempt has been made to determine the effective volume of the notched specimens due to the general lack of understanding of the Boussinesq effect adjacent to the reduced portion. Standard tension impact specimens were used to permit direct comparison with published data for other materials.

MR. R. A. LINCOLN[4] (*by letter*).—I believe that in the past there has been too much tendency to accept the yield strength at which 0.2 per cent set takes place, the tensile strength and the percentage elongation as a description of the mechanical properties of a material. This paper by Mr. Muhlenbruch gives us another interesting procedure through which the mechanical properties of a metal can be considered.

I found his reference to the shape of the stress-strain curve especially interesting. High tensile cold-rolled type 301 stainless steel strip has a stress-strain curve whose shape is greatly different from that of the other materials discussed in this paper. With high tensile cold-rolled type 301 stainless steel strip, the stress-strain curve has a relatively low proportional limit and a considerably higher stress at which 0.2 per cent set takes place. In other words, the stress-strain curve ceases to be linear at a relatively low stress, but after the proportional limit is exceeded the deviation from straight line behavior takes place very gradually as the load is increased. Even after the stress at which 0.2 per cent set takes place is exceeded, the stress-strain curve continues to rise, and further increase in strain results in an appreciable increase in stress. Thus the point on the stress-strain curve where 0.2 per cent set takes place has no significance for defining the upper limit of load-bearing ability of this metal.

In order to describe the load-bearing characteristics of high-tensile cold-rolled type 301 stainless steel strip, it is necessary to consider the tangent modulus of the stress-strain curve at the stress under consideration. When the tangent modulus of the material is plotted against stress, it will be found that it changes very gradually with increasing stress, and useful values are obtained at stresses considerably over the value at which the yield strength is located.

The other materials discussed in this paper do not show such relationships. The proportional limit in these materials is relatively high, and after it is exceeded the tangent modulus falls off rapidly and the yield strength is located at a stress not greatly in excess of the proportional limit. With these other materials when the yield strength is exceeded, the stress-strain curve tends to flatten out and further increase in strain produces only a slight increase in stress. Thus, for such material, the yield strength at which 0.2 per cent set takes place is a criterion of the upper limit of load-bearing ability.

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[4] Allegheny Ludlum Steel Corp., Brackenridge, Pa.

These relationships are not new and have been discussed in a paper by W. Ramberg and W. R. Osgood entitled "Description of Stress-Strain Curves by Three Parameters" published as Technical Note No. 902 by the National Advisory Committee for Aeronautics. In order to correctly predict the load-bearing ability of light gage structures made from high-tensile cold-rolled type 301 stainless steel strip, it is necessary to take the above factors into account and follow a design procedure such as is indicated in a book by Timoshenko entitled "Theory of Elasticity" under the subject of design beyond the proportional limits. When such factors are taken into account it will be found that short columns of low slenderness ratio fail at stresses considerably over the yield strength, and calculations are checked by experimental results. Thus, with full hard type 301 stainless steel strip that has a yield strength of 145,000 psi., a relatively short column with a slenderness ratio of 14 will be found to have a critical column stress of approximately 170,000 psi.

By way of summary of the above, the yield strength which has such wide significance in most metals has relatively little significance when dealing with cold-rolled high-tensile stainless steel strip. Failure usually occurs either when some parts of the structure are subjected to stresses at which it is structurally unstable in either compression or shear or, if the failure is in tension, it is at a stress considerably higher than the stress, at which 0.2 per cent set takes place on the stress-strain curve.

Thus, the properties of type 301 cold-rolled stainless steel strip described by Mr. Muhlenbruch agree well with the general properties of this material.

MR. MUHLENBRUCH (*author*).—Mr. Lincoln points out properly that the yield strength of high-strength stainless steel is really not a criterion for structural instability analogous to the yield strength of aluminum or the yield point of structural steel. It is pointed out in the paper that the elastic toughness of stainless steel increases much more than that of aluminum when the permanent set is increased from 0.2 per cent to 0.3 per cent. Structural designers employing high-strength stainless steel will do well to study the references given by Mr. Lincoln.

DYNAMIC CREEP AND RUPTURE PROPERTIES OF TEMPERATURE-RESISTANT MATERIALS UNDER TENSILE FATIGUE STRESS*[1]

By B. J. Lazan[2]

Synopsis

The limitations of static testing and the importance of dynamic creep and rupture properties in designing for high-temperature service are discussed. Newly developed dynamic testing machines and measuring equipment for determining creep and rupture properties are described. Data on several temperature-resistant materials are presented within mean-stress - alternating-stress coordinates to show the influence of dynamic stress on creep and time to rupture. The relationships between testing temperature and dynamic stress influence on creep and rupture are shown. The increased creep and rupture resistance during some of the dynamic tests is discussed in terms of possible metallurgical changes caused by cyclic stress. Data presented show the greatly decreased ductility caused by the superposition of cyclic stress on tensile preload.

Recent developments in gas turbines, propulsion engines, and other high-temperature applications have demonstrated the greatly increased efficiency possible with materials which can withstand high stresses at high temperatures. This work has also emphasized the importance of developing new materials to permit still higher stresses and temperatures. The engineering implications of higher allowable temperatures and working stresses have stimulated considerable activity among metallurgists and other materials engineers to develop new and improved materials, processes, and treatments, and also among design engineers to utilize existing materials under the highest possible operating temperatures and stresses.

Both the materials engineer and the design engineer have a very strong common concern in one important phase of the broad problem, that of evaluating the serviceability of existing and newly developed materials by suitable test methods. The materials engineer must rely on materials test data to determine the improvements in properties offered by newly developed materials, to correlate these improvements with composition, constitution, processing and treatment, and to establish trends for guiding future developments. The design engineer must know the correlations among stress, deformation, rupture, time, temperature, environment, elasticity, and other properties in order to produce the most efficient design possible with the available materials. Aside from the developmental aspects of the problem, both the metallurgist and the design engineer have a common interest in testing as a means of production quality control of temperature-resistant materials.

Although there is general agreement that materials testing constitutes an important phase of engineering development, particularly where severe service conditions are to be expected, there is usually disagreement as to which type of test most effectively reveals the fundamental properties and service behavior of materials and parts. In this connection, materials testing may be classified as follows:

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] This work was sponsored by the Air Materiel Command Contract W-33-038 AC-15941 (17507).

[2] Professor and Head, Department of Materials Engineering, Syracuse University, Syracuse, N. Y.

1. Testing of carefully prepared specimens under simplified conditions of stress and environment to determine what might be termed the fundamental properties of the material.

2. Testing of actual parts and assemblies (or parts slightly modified to permit gripping, etc.) under conditions which closely simulate the critical stress and environment encountered in actual service.

3. Testing of actual parts and assemblies in actual service.

These three types of testing are listed above in order of increasing validity for predicting serviceability but also in order of increasing cost and difficulty, in most cases. That is, no test of serviceability is as "foolproof" as actual service. However, to rely exclusively on actual service is usually impractical, time consuming, and extremely expensive, particularly in a material development program in which the fundamental properties of the materials are not known. Consequently, a well-balanced engineering program generally includes all three types of testing.

The particular type of test justifying most emphasis generally depends on the state of knowledge in the field. If little is known about the basic properties of the materials, let alone the behavior of the actual part in simulated service conditions or in actual service, then specimen tests of type 1 should generally be emphasized as a first step in the program. Knowing the basic properties of materials, the results procured in subsequent tests of type 2 and 3 are generally more easily interpreted and measures for improvement are more apparent.

In the particular problem under consideration, that of evaluating temperature-resistant materials for high-stress service, considerably more information on the fundamental properties of specimens is necessary for efficient metallurgical and mechanical development. Consequently, work described in this paper concentrates on specimen testing.

Although specimen testing is generally accepted as a proper first step, there is usually disagreement as to which particular type of specimen testing is most fundamental, most revealing, and which simulates service most closely. In high-temperature, high-stress applications, the important commonly used tests in this country for evaluating materials include the following, in approximate chronological order.

(*a*) Short-time static tension tests,
(*b*) Rupture under prolonged static forces,
(*c*) Creep under prolonged static forces, and
(*d*) Fatigue tests under dynamic forces.

In view of the complexity of actual service, in which a number of different critical conditions in varying proportions are likely to occur, it is unlikely that any one of the above simplified tests, or any modified or new simple test, can provide an accurate index of serviceability. In general, therefore, it is usually necessary to give weighted consideration to several basic properties in order to arrive at such an index. In the high-temperature field, tests which reveal creep and rupture characteristics under static loading (tests *b* and *c* above) are the most commonly used means of rating serviceability. However, temperature-resistant materials used in gas turbines, propulsion engines, superchargers, and other types of high-temperature service rarely receive purely static forces; cyclic or fatigue stress is usually superimposed over static loading.

The present-day trend toward higher speeds and lighter weight construction has increased the prominence of vibrations as a factor in design. Therefore, fatigue testing (test *d* above) of temperature-resistant materials is gaining new importance in recent years. However, it is likely that fatigue loading affects the creep properties and both generally contribute to service failure. Therefore, individually obtained static creep[3] and fatigue data, although valuable, are probably less significant than data giving the general relationships among stress,[4] deformation,[5] time, temperature, and chemical environment.[6] The work described in this paper is the beginning of a broad material evaluation program which is to include the analysis of the fundamental factors affecting the behavior of temperature-resistant constructional materials.

In the interest of better understanding the fundamental behavior of temperature-resistant materials under dynamic stress, and as a first step in this program, a study was undertaken of the dynamic creep and rupture properties of temperature resistant materials at elevated temperatures under a combination of static tensile preload with an alternating direct stress superimposed. Although this type of dynamic stress was selected primarily because of its fundamental nature, it is also reasonably close to that encountered in some types of service. In turbine blades, for example, the bending vibrations caused by aerodynamic forces are generally superimposed over the large centrifugal force caused by high rotary speeds. The outer surface of the blade, the most likely origin of failure, is therefore subjected to a combination of static tension stress with alternating direct stress superimposed.

Previous dynamic testing work has been concentrated almost exclusively on rupture or fatigue properties. Dynamic creep data (extension under dynamic force), although extremely important in some types of service, are practically nonexistent. In the Syracuse work both dynamic rupture data and dynamic creep data are determined under different combinations of mean and alternating tensile stress. In some dynamic stress regions, creep may govern the magnitude of the allowable stress, whereas in other stress regions the time to actual rupture may be the more important. In many cases, both creep and time to rupture under dynamic loading, and not just rupture time, must be known if intelligent working stresses and temperatures are to be selected, if new and old materials and treatments are to be evaluated and compared, and if the fundamental behavior is to be better understood.

REVIEW OF PRIOR RESEARCH ON DYNAMIC CREEP

Only German literature could be located in which recognition and special attention was given to dynamic creep. Hempel and Tillmans (**1**)[7] in 1936 conducted tests on carbon, molybdenum, and chromium-nickel steels at temperatures up to 600 C. A hydraulic pulsator type of machine with a frequency of 50 or 500 cycles per min. was used in which creep was measured at the crosshead of the machine. Although the test data display rather large scatter, the presence of dynamic stress does not appear to affect greatly the creep. In the opinion of Hempel and Tillmans creep under dynamic tension is approximately the same as at a static tension equal to the upper limit of the dynamic test for the materials studied. Furthermore, they observed that frequency does not seriously affect dynamic creep in the tests undertaken.

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[3] Creep used in the broad sense to include complete separation or rupture.

[4] Stress used in the broad sense to include static and dynamic (variable) stress.

[5] Deformation used in the broad sense to include elastic and plastic deformation, creep, and rupture.

[6] The environment factor is particularly important under repeated stress conditions due to the accelerated effects corrosion exerts on fatigue failures.

[7] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 787.

In 1938 Bernhardt and Haneman (2) determined the dynamic creep of lead at room temperature. Forces were applied by a crank-spring arrangement (with questionable inertia forces due to near resonant vibrations) and deflections were measured by an optical system attached to the specimen. These investigators found that dynamic creep is almost linearly proportional to frequency, that the constant rate second stage creep is reached more rapidly under dynamic forces than under static forces, and that a correlation exists between damping capacity and dynamic creep.

Gurtler and Schmid (3) in 1939 published dynamic creep and rupture data for iron, several carbon steels, aluminum, copper, zinc, and lead. These authors presented Goodman type stress-range diagrams for both dynamic rupture and dynamic creep which indicate that the higher the temperature the more important is dynamic creep compared to dynamic rupture.

In 1942 Hempel and Krug (4) studied dynamic rupture and creep of chromium-molybdenum steels from 20 C. to 500 C. with a 666 cycles per min. hydraulic pulsator. The data presented indicate the necessity of considering both dynamic creep and fatigue in some cases before a range of dynamic stress is known to be safe at a certain temperature. In certain stress-range regions fatigue failure governs, whereas in other regions dynamic creep consideration may necessitate use of a stress considerably lower than the fatigue strength. The temperature range and type of material greatly affect the relative importance of the two factors. In general, dynamic creep strength is more adversely affected by increasing temperature than is fatigue strength.

In 1940 the author undertook a few exploratory tests (work unpublished) to determine the effects of superimposed cyclic stress applied by a centrifugal force type of oscillator (7) on the creep of 2-SO and 3S-$\frac{1}{4}$H aluminum wire at room temperature. He found that, for the few specimens tested, low magnitude cyclic stress (lowest or trough stress was 55 per cent of highest or crest stress) causes a larger first stage total creep, an earlier commencement of second stage creep, and a lower second stage creep rate than is produced by a static load equal to the highest or crest value of the dynamic load. Under these conditions the total creep for the first few days is larger under the dynamic load than under the static load, but the creep curves cross and subsequent creep under dynamic load is considerably smaller than under static load. In another test, with cyclic stress equal to 75 per cent of the mean stress, the total creep was found to be approximately 80 times as large as the creep at a static stress equal to the mean dynamic stress. However, in view of the possible variability of the test material, there are insufficient test data to permit definite conclusions.

In the current Syracuse work the creep and rupture properties under various combinations of static preload and alternating stress applied at 3600 rpm. are determined at 1350 F. and 1500 F. for several temperature-resistant materials. The type of dynamic stress imposed on the test specimens is shown in Fig. 1. The stress S at any instant of time can be represented by the sine function:

$$S = S_m + S_a \sin ft$$

where:

S = instantaneous stress,

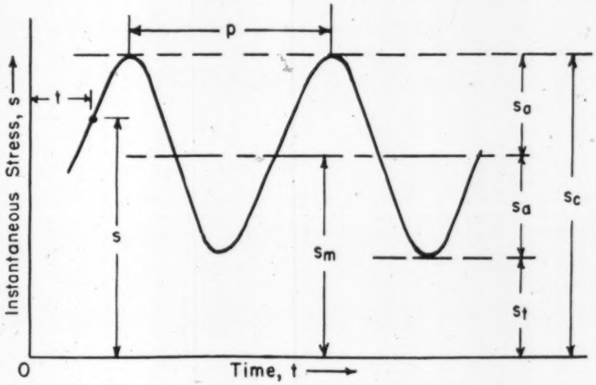
S_m = mean stress or static preload imposed,

S_a = alternating or cyclic stress superimposed over the static preload,

f = frequency of the cyclic or vibratory stress, and

t = time.

The newly developed Syracuse equipment can apply any combination of mean stress S_m and alternating stress S_a under controlled conditions.



S = Instantaneous stress = $S_m + S_a \sin ft$
S_a = Alternating stress = $S_m - S_t$
S_c = Crest stress = $S_m + S_a$
A = Vibration alternating—mean ratio= $\frac{S_a}{S_m} = \frac{1-T}{1+T}$
f = Frequency of vibration = $2\pi/P$
S_m = Mean stress = $S_t + S_a = S_c - S_a$
S_t = Trough stress = $S_m - S_a$
T = Vibration trough—crest ratio= $\frac{S_t}{S_c} = \frac{1-A}{1+A}$

FIG. 1.—Cyclic Stress Definitions.

TESTING EQUIPMENT

A study was made of existing equipment capable of (*a*) imposing an adjustable static tensile preload, (*b*) maintaining this tension constant even under large creep, (*c*) superimposing an adjustable alternating direct force at a reasonably high frequency, and (*d*) maintaining this alternating force constant even under changing specimen elasticity. Hydraulic pulsators and crank type machines such as used by German investigators (**1, 2, 3, 4**) were too slow, too elaborate, or included doubtful inertia force correction factors difficult to determine accurately. In existing American machines, at the time this work was planned in 1946, either the alternating force was difficult to control accurately under conditions of changing specimen stiffness, the testing speed was too slow, or the static preload could not be accurately maintained under creep conditions. It was therefore decided to develop a new machine similar in principle to one previously developed by the author (**6**) but including provisions for maintaining preload under all conditions of creep and including other refinements required in high-temperature testing.

The principle of operation of this machine is illustrated in the schematic diagram of Fig. 2 and the photograph of Fig. 3. The test specimen C is held by the two self-aligning, spherically seated specimen holders A and D, and located so that it rests within the uniform heat zone of special creep furnace B. The lower end of specimen holder D is pulled downward by the cage E which is guided by four flexplates M. Contained within the oscillating cage is a revolving eccentric mass *F* which is the source of the axial vibrations imposed on the specimen. Attached to the lower end of the cage *E* are flexible preload springs *G*, the lower end of which are pulled downward by adjustable lower crosshead *J*. These springs exert the static tensile preload applied to the test specimen. The force in preload springs *G* is increased by lowering adjustable crosshead *J* by means of worm drive *K* and is decreased by raising the adjustable crosshead. The dynamic component of the tensile load, produced by revolving eccentric mass *F*, is a sinusoidal vertical force transmitted through the cage and lower specimen holder to the test specimen.

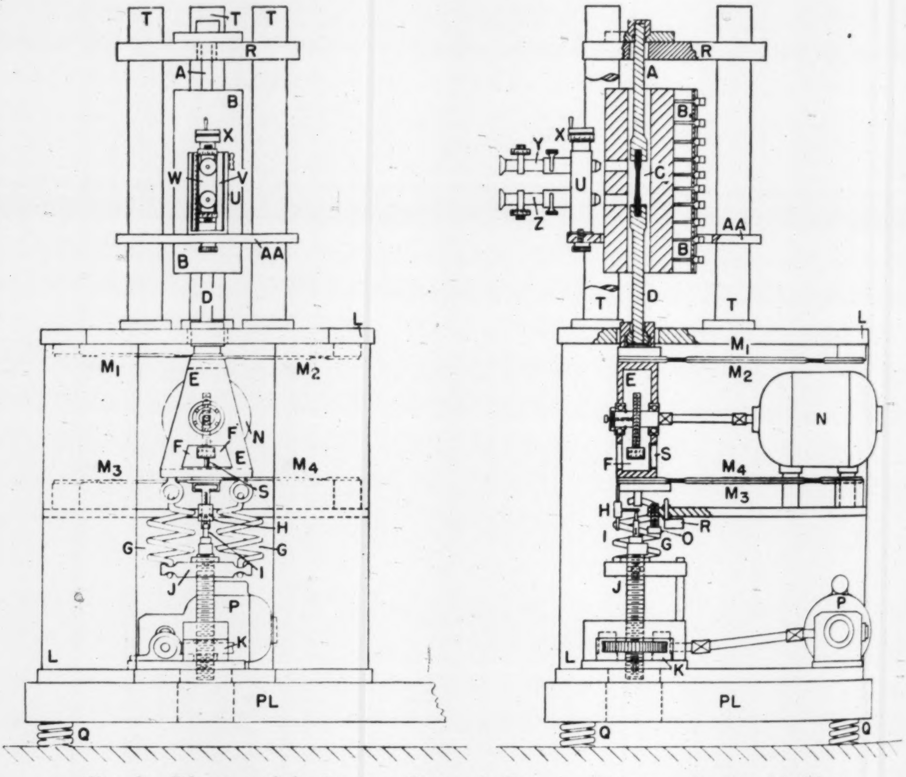


FIG. 2.—Diagram of the Syracuse Dynamic Creep and Rupture Testing Machine.

The flex-plate system shown guides the cage so that only vertical motion is permitted. Thus the horizontal component of the centrifugal force produced by the revolving eccentric mass is resisted by the flex plates, and only the vertical component is transmitted to the specimen. The vertical alternating force produced by the eccentric may be determined from the equation:

$$F = Mrf^2 \quad \ldots\ldots\ldots\ldots (1)$$

where:

F = plus or minus alternating force produced by the eccentric *F*,

M = mass of the eccentric,

r = distance between center of gravity of the eccentric and the axis of rotation, and

f = speed of rotation of the eccentric.

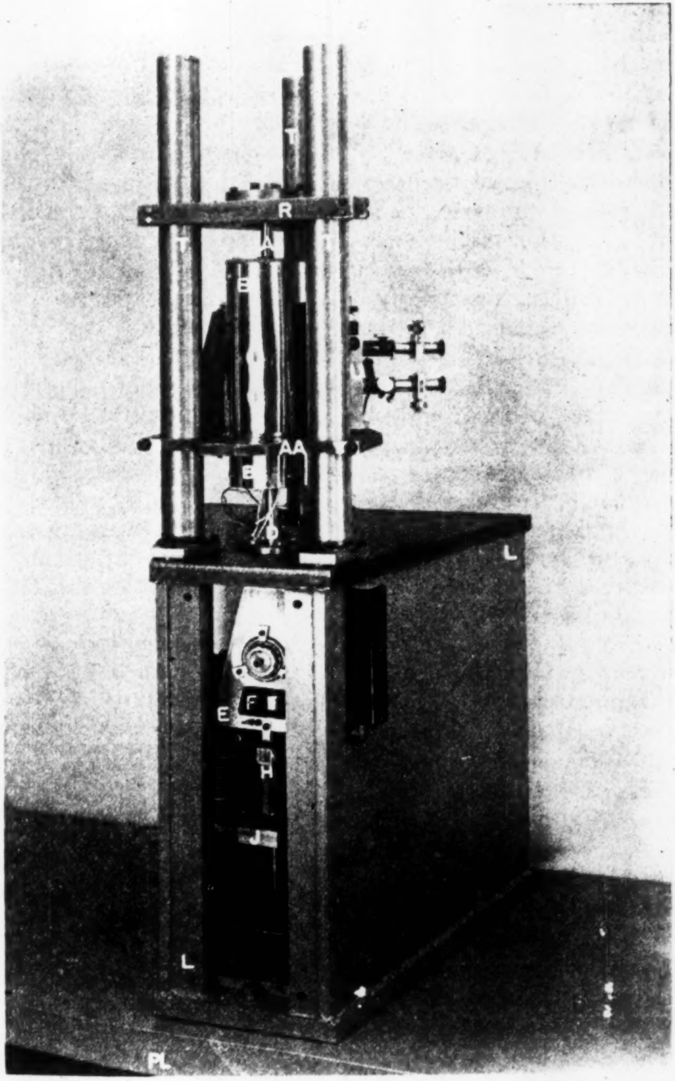


FIG. 3.—Photograph of the Syracuse Dynamic Creep and Rupture Testing Machine.

The alternating force felt by the test specimen is the vector sum of the following two components:

1. The force produced by the revolving eccentric as determined by Eq. 1
2. The inertia force caused by the vibrating parts between the bottom of the specimen and the loading springs.

The effective magnitude of this inertia force depends on the phase angle between the force and displacement during the vibration.

The revolving eccentric mass is a calibrated screw assembly with divisions marked on the head of the mass and along scale S so that the position of the eccentric may be read like a micrometer screw. Thus, the "Mr" factor in Eq. 1 is accurately known. Since the eccentric mass is driven by a synchronous motor at a speed of 3600 rpm. irrespective of load, the "f" factor in the equation is known. Thus, the centrifugal force can be calculated with considerable accuracy.

The inertia force term, may, under certain conditions, be cancelled by inertia force compensator springs (6). However, in this creep and rupture machine it is highly desirable, as explained later, to use extremely flexible preloading springs, too flexible to compensate effectively for inertia forces. In view of this condition, the mass of all vibrating parts which affect the inertia force correction (mass between lower end of specimen and springs) was kept as small as possible so as to minimize the inertia force correction. Furthermore, a small effective mass at the lower end of the specimen results in an operation frequency well below the fundamental resonant frequency of the system, and the vibration phase angle is zero. Thus, the inertia force correction, which averages approximately 7 per cent for the machines used, can be accurately determined.

Even though the two components of the alternating force can be accurately determined, the machines received a final calibration with a specially adapted proving ring. The vibrating reed in the standard proving ring is not suitable for measuring alternating forces and therefore was replaced with a specially designed and constructed electric contact device. Room temperature calibration tests were also made with wire resistance strain gages.

During a few of the early tests the excessive creep observed immediately after starting the alternating stress in a test indicated that the specimen was probably overloaded due to inertia effects caused by the rapid starting characteristics of the synchronous motors used. This suspicion was confirmed by proving ring measurements. Consequently, the starting and control box now includes variable transformer equipment so that the synchronous motors may be started slowly by building up the motor voltage slowly. Measurements show that this starting procedure does not overload the specimen.

The preload springs G are carefully calibrated so that the force at any extended length is accurately known. The extended length of the preload springs is accurately indicated by the vernier slide arm H. This preload is automatically maintained during the course of the test, even though large creep may occur in the test specimen, by the following control system. Before starting a test, the vernier slide arm H is set and locked at that reading of the vernier scale which produces the desired extension in the springs. This adjustment depresses microswitch I which starts preload motor P and causes the worm drive K to lower the adjustable crosshead J until the microswitch ceases to contact vernier slide arm H. Thus the extension in the springs is kept at that value which produces the desired spring force. Since the static force in the springs is transmitted through the cage to the test specimen, a constant preload is maintained on the specimen.

Should the test specimen creep during the test, cage E would be slightly lowered and the vernier slide arm will contact the microswitch I, which results in adjustment of lower crosshead J to maintain constant spring extension (constant preload force in the specimen). Thus, irrespective of the magnitude of creep, the control system will maintain constant preload. The preload springs are designed to be extremely flexible (extension at full load greater than 2 in.) so that the control and measuring system need not be excessively sensitive and also so that the change in force in these springs required to cause the control system to be operative is negligible.

One difficulty experienced during operation of this follow-up system was "freezing" of the microswitch. At the control point the switch actuator, vibrating with the oscillator frame, trips the switch 3600 times a minute, which is too fast for the preload motor to respond. The resulting arcing is likely to weld the microswitch contacts together and therefore make the follow-up system inoperative. This difficulty was solved by incorporating time delay relays in the follow-up circuit so that once the first contact is made the preload motor remains on for about two seconds, thus avoiding arcing.

The upper crosshead *R*, which holds upper specimen arm *A* is vertically adjustable and may be locked to columns *T* in any position by a friction type clamp. Bracket *AA*, also vertically adjustable on columns *T*, supports furnace *B* and the measuring microscope assembly. An adjustable bumper *O* under the cage catches the cage assembly when the test specimen breaks, and a microswitch shuts off the machine and furnace.

The entire assembly is held by frame *L* bolted to heavy baseplate *PL* which is seismically mounted on springs so as to isolate the machine vibrations from the floor. Originally each machine was individually mounted on seismic springs. However, the vibrations during operation were excessive from point of view of (*a*) the inertia force correction and (*b*) the ability of the micrometer microscope equipment to withstand vibration. Consequently, in the final arrangement three or four dynamic machines are mounted to each of two baseplates so that the weight of the battery of machines and baseplate help to stabilize each machine. The disadvantage of this approach is that each running machine will have a very small, usually negligible, inertia effect on all other machines attached to the same baseplate. However, the advantages gained by this approach far exceed the disadvantages.

The machines and fixtures described above are designed for dynamic testing in the tension region only. Recent improvements, not described in this paper, now permit testing in the compression region also.

A partial view of the Syracuse Dynamic Creep and Rupture Laboratory is shown in Fig. 4. This laboratory has two static machines and seven dynamic testing machines, partially shown bolted to base plates *PL* seismically mounted on helical coil springs *Q*. Each machine has an independent temperature control panel shown in the rear.

CREEP-MEASURING EQUIPMENT AND PROCEDURE

After due consideration of accuracy, simplicity, and flexibility of various creep-measuring systems, it was decided to use a double micrometer microscope method. The microscope assembly for sighting on targets to measure creep was specially developed for this work and is shown in Fig. 5. Microscopes *Y* and *Z*, with movable cross-hair type of micrometer head *A* and *B*, are attached to slide *W*. Frame *V* guides slide *W* which is moved vertically by means of the micrometer hand wheel *X*.

To measure small values of creep and vibration amplitude, the microscopes are positioned by micrometer head *X* and the actual measurements are made with micrometers *A* and *B*. Large creep, beyond the range of micrometers *A* and *B*, may be measured by micrometer head *X*. Frame *V* is seismically supported within support *U* by means of three rubber type springs *D* of proper spring constant. Thus, even though support *U* is rigidly attached to the machine and vibrates with it during measurement, the magnitude of the high-frequency vibrations in the seismically mounted micrometer microscope assembly is greatly reduced. This not only improves measuring accuracy but also prolongs microscope life.

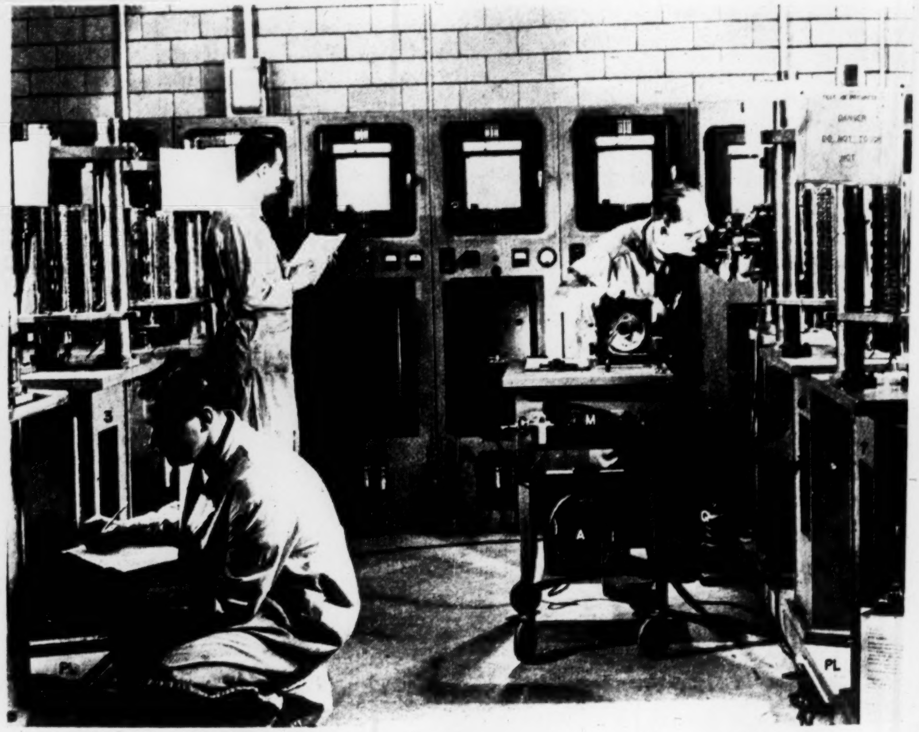


FIG. 4.—Partial View of the Syracuse Dynamic Creep and Rupture Laboratory.

The microscope assembly is positioned and clamped in front of the measuring windows in the furnace by means of three balls which fit in conical holes in the bottom of bracket *U*. Three such sets of three balls are adjustably attached to bracket *A A* in Fig. 2 so that readings may be taken on any one pair of the three pairs of specimen targets spaced at 120-deg. By taking the three 120-deg. readings, the stress distribution in the test specimen may be determined.

A stroboscopic light source is used for this microscope equipment so that the vibrating measuring targets on the test specimen may be viewed in either the "slow-motion" or "stopped" position. The controls for this stroboscope and its method of use are shown in Fig. 4. The light source *L* for the microscope targets is flashed at the operating frequency of the machine (3600 cycles per min.) by means of mechanical contactor and phase shifter device *C* driven by small synchronous motor *M*. Since both the flashing frequency and the vibration frequency are equal, the specimen targets appear stationary and their position can be conveniently read on the micrometer microscope.

However, it is important to read the target consistently at the same position of its vibration cycle. The target position is therefore measured when the eccentric is vertically downward at the instant of greatest tensile stress during the stress cycle. This is done for reasons of consistency and also because the flash phasing is less critical at the peak stress values, when the target velocity is a minimum, than elsewhere. To accomplish the above phasing a second stroboscope *A*, actuated by the same mechanical contactor and therefore flashed synchronously with the microscope stroboscope, is placed to illuminate the eccentric. The procedure is to adjust the contactor *C* until the eccentric mass as viewed stroboscopically appears to be vertically downward and then the target position is read with the measuring microscopes.

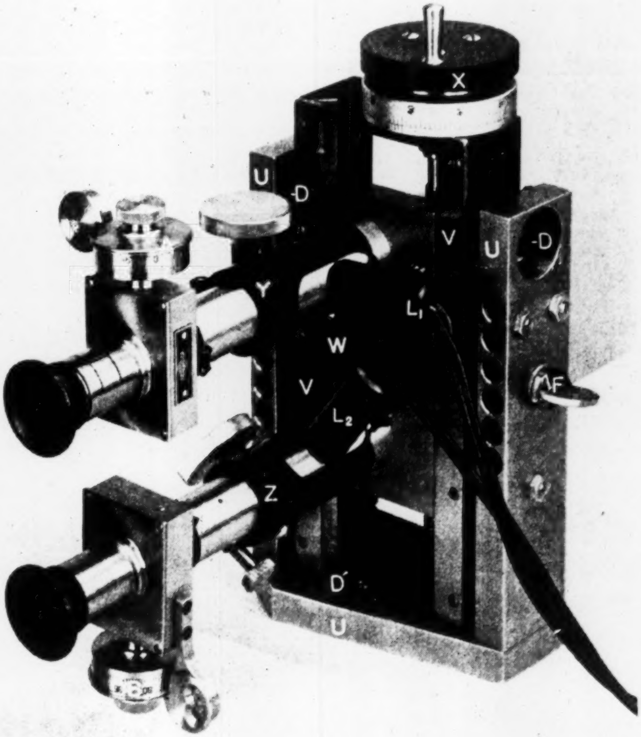
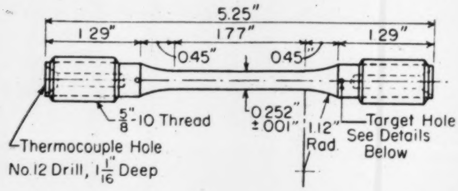
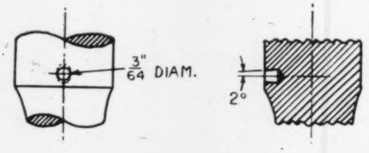


FIG. 5.—Stroboscopic Micrometer-Microscope Assembly.

During the first dynamic tests microscope targets were scribed on platinum strips wired to the enlarged shoulders of the test specimen, which were grooved to accommodate the wires. However, it was found that prolonged vibrations loosened such strips due to creep and relaxation in the fastening wire at the high temperatures. An attempt was then made to plate platinum directly on the enlarged shoulders of the specimens. It was felt that if the plate could be made to withstand 1500 F. there would be less possibility of slip or creep between target and specimen during prolonged dynamic tests. At the same time the threaded ends of the test specimen could be plated so as to make removal of the corroded specimen after a long test less difficult. However, although a plating which was sound at room temperature could be produced, blistering and peeling of the plate occurred at the elevated testing temperature. Several corrective measures were attempted, and since none proved to be wholly successful, this plating approach was abandoned. The targets next investigated include spot welded platinum disks, small platinum screws, and peened platinum plugs. The simplest approach which proved successful is described below.



Test Specimen Dimensions



Enlarged Shoulder Showing Target Hole Details

FIG. 6.—Specimen for Dynamic Creep and Rupture Tests.

Six small holes are drilled in the enlarged shoulders of the test specimen shown in Fig. 6 so that the root of the holes are larger than the mouth of the holes. This is accomplished by slightly rotating the specimen (approximately 2 deg.) about an axis perpendicular to the drill at the point where the drill enters the specimen. Short lengths (approximately $\frac{1}{16}$ in. long) of platinum wire of diameter equal to the mouth of the hole (approximately $\frac{3}{64}$ in.) are then placed in these holes and peened with a special tool so as to upset and expand the bottom or root end to fit the wedge-shaped contour of the hole. The shoulders of the specimens and the platinum plugs are then polished and a very fine dot is scribed on each plug to provide targets for the measuring microscopes. This approach requires only a small amount of platinum (approximately 10 cents per target) and provides an extremely secure base for the target.

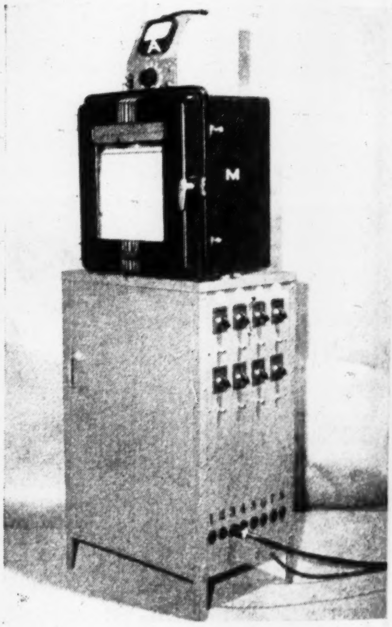


FIG. 7.—Autographic Creep Recorder.

Other equipment used for creep measurement and autographic recording is shown in Fig. 7. In this equipment (10), the output of a linearly variable transformer attached to the lower end of grip *D* (Figs. 2 and 3), outside the furnace, is divided by sensitivity switches *S*, rectified by A, and recorded by multipoint recorder M. Since grip and machine expansions and contractions under temperature change and specimen thread effects are included in this measurement, this creep recording device can be used only in tests with large creep or as a check on the microscope method and during overnight runs.

FURNACES AND TEMPERATURE CONTROLS

Special furnaces were constructed with two windows, one opposite each sighting target, at 120 deg. spacing around the circumference. Such measurement at 120 deg. provides a means of evaluating the eccentricity of the static and alternating load so that corrective measures can be taken to assure a uniform stress distribution on the test specimen.

Temperature distribution within the furnaces is measured with a special calibration assembly containing three thermocouples along the test section of the specimen and two end thermocouples, one in each hole in the enlarged portion at each end of the specimen (see Fig. 6). Shunts on the furnace are adjusted so that all five thermocouples are registering within ±5 F. of the desired temperature. During an actual test only two thermocouples are used, one in each end hole, and their temperatures are measured before starting a test to assure temperature uniformity within the desired limit. One of these two thermocouples is used for control purposes during the test, and the second is used for checking purposes and as a standby.

Each furnace has its own temperature control panel consisting of a Leeds & Northrup micromax recording potentiometer operating through a Thyratron Tube Reactrol control for four units and through a Leeds & Northrup MED-DAT controller for the remaining five units. These proportioning units maintain the control thermocouple constant in temperature within ±3 F.

THE TEST SPECIMEN AND ITS PREPARATION

The shape of the test specimen is shown in Fig. 6. The test section is 0.252 in. in diameter and has a 1.12 in. fillet on each end. The straight section of 1.77 in. was calculated to provide a mathematical gage length of 2 in. so as to simplify creep calculations. That is, from stress *versus* creep data each fillet was calculated to be approximately equivalent to 0.115 in. of straight test section length and the mathematical or effective gage length is therefore 1.77 + 0.115 + 0.115, or 2.00 in. total. A straight test section of this type, although not essential for fatigue or rupture data, is required for creep measurement.

Since, in the dynamic creep and rupture tests, dynamic stress constitutes a large percentage of the total load, particular attention to the surface finish is necessary. Although normal surface finishes are generally acceptable for the static creep and rupture test, the dynamic tests under discussion require a surface finish comparable to that required for a fatigue test specimen if stress concentration effects are to be avoided. Furthermore, the scratches should be longitudinal (as in a rotating-beam fatigue test specimen) so that stress is parallel rather than perpendicular to the scratches.

The first attempt at finishing the specimens as described above was with a 2.25 in. diameter grinding wheel (1.12 in. radius same as fillets in test specimen). The specimen was slowly rotated in a lathe as the grinding wheel was operated at high speed with its axis of rotation perpendicular and offset 1.12 in. from the surface of the specimen. However, this approach was found to be impractical. The small diameter of the specimen and its long 2 in. gage length (unlike the usual fatigue specimen whose test section frequently consists of one liberal fillet) and the small diameter of the grinding wheel resulted in wheel chatter, wear, etc., and a suitable surface finish could not be produced. After considering several other methods of finishing the test specimens, the following belt sanding method was developed.

A photograph of the specimen finishing setup is shown in Fig. 8. Test specimen *S* is slowly turned on centers in the lathe shown. Attached to the carriage *A* of the lathe is an endless belt sander *B* to which is attached a hardened guide block *C*. An endless sanding belt *D* with specially constructed constant thickness lap joints is run over this guide block. The shape of guide block *C* is such as to produce the desired contour in the test specimen, and the specimen diameter is controlled by positioning the carriage *A* as necessary. Lever *E*, which positions the axis of rotation of the right-hand pulley over which the sanding belt runs, may be used to oscillate the sanding belt vertically so that different regions of the belt are placed in the sanding position behind the specimen. Thus, practically the entire width of the sanding belt may be used effectively, resulting in prolonged belt life and improved specimen finish. Specimens are belt sanded under a constant flow of coolant from nozzle *L* so as to avoid overheating of the surface of the specimen. Also sharp sanding belts and low pressures are used to minimize surface distortion effects (8). A 100 grit belt is used first for specimen contour adjustment, followed by a 280 and 500 grit belt for finish. Specimens are finished true within a few ten-thousands of an inch, and the surface has the high polish required for fatigue specimens. This method has proved to be an adequate solution to the specimen finishing

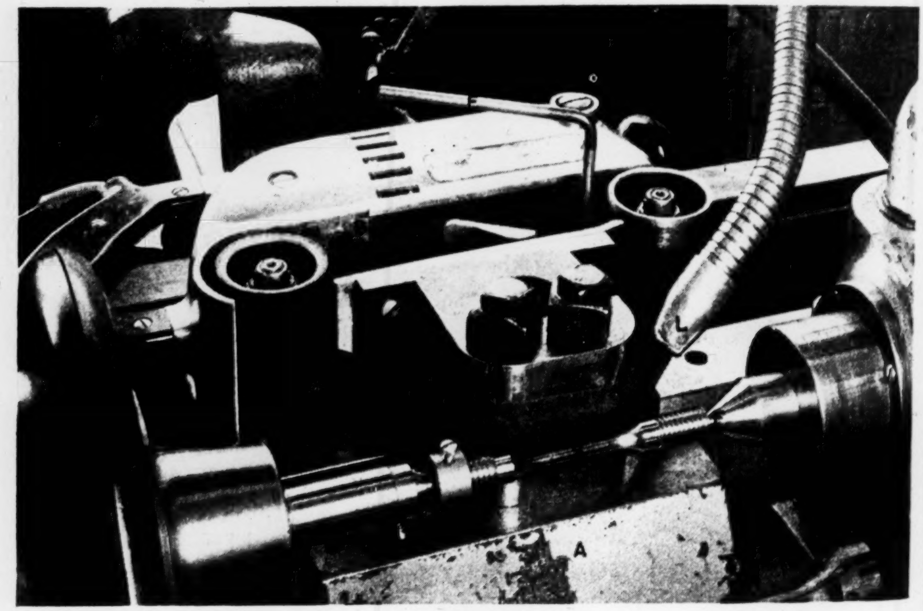


FIG. 8.—Setup for Finishing Test Specimens.

TABLE I.—TEST MATERIALS.

Material Designation	N	S	V	D
Commercial name	N-155	S-816	Vitallium	19-9DL
Supplier	Universal Cyclops Steel Corp., Titusville, Pa.	Alleghany Ludlum Steel Corp., Watervliet, N. Y.	Haynes Stellite Co., Kokomo, Ind.	Universal cyclops Steel Corp., Titusville, Pa.
Heat number	A-11534[a]	42008	573	B-10429[a]
Initial form of raw material	9-in. billet from 10,000-lb. arc-furnace	6-in. cast ingot	Precision cast	9-in. billet from 10,000-lb. arc-furnace
Delivered form of raw material	Upset Disk-21 in. diameter by 3.25 in. Finished at 1630 F.	Rolled into 0.78 in. diameter bars. Water quenched from 1950 F. Centerless ground to ¾ in. diameter.	Precision cast	Upset Disk-19.2 in. diameter by 3.25 in. Finished at 1640 F.
Final heat treatment	Disk stress-relieved at 1200 F. for 2 hr. air cooled	Water quenched rom 2300 F. Aged at 1400 F. for 2 hr. Furnace cooled.	Aged at 1350 F. for 50 hr. Furnace cooled	Disk stress-relieved at 1200 F. for 2 hr. air cooled.
Micrograph shown in figure	9	10	11	12
Rockwell "A" hardness	56 to 62.5	64 to 65	68.5 to 71	56.5 to 61.
	Chemical Composition, per cent			
Carbon	0.15	0.42	0.28	0.33
Manganese	1.74	1.03	0.60	1.14
Silicon	0.37	0.30	0.69	0.65
Chromium	21.7	19.8	26.7	19.1
Nickle	19.4	20.2	2.7	9.1
Cobalt	19.0	44.1	61.8[b]	....
Molybdenum	2.76	3.70	5.9	1.35
Tungsten	1.90	3.86	....	1.14
Columbium	0.79	3.82	....	0.35
Nitrogen	0.14	....	....	....
Iron	32.1[b]	2.60	1.3	66.6[b]
Sulfur	....	0.014	....	0.015
Phosphorous	....	0.016	....	0.016
Titanium	....	....	....	0.16

[a] Originally furnished to Battelle Memorial Institute (5).
[b] Balance.

problem. However, the magnitude of surface distortion and its significance in turns of specimen properties have not yet been evaluated.

TEST MATERIALS

The test materials, suppliers, heat numbers, the initial and final form of the raw material, hardness, and chemical composition data are given in Table I. The heat treatment used in preparing the test specimens is not necessarily the best for resisting the imposed loads; rather, it is generally the same as that used in previous static work (5) so that more direct correlation is possible.

The specimen numbers used have the following meaning. The prefixing letter designates the material as indicated in Table I. Specimens machined from the forged disks (N-155 and 19-9-DL) were assigned the suffixing letters X, Y, and Z to designate radial location on the top, middle, and bottom, respectively.

All hardness measurements were made

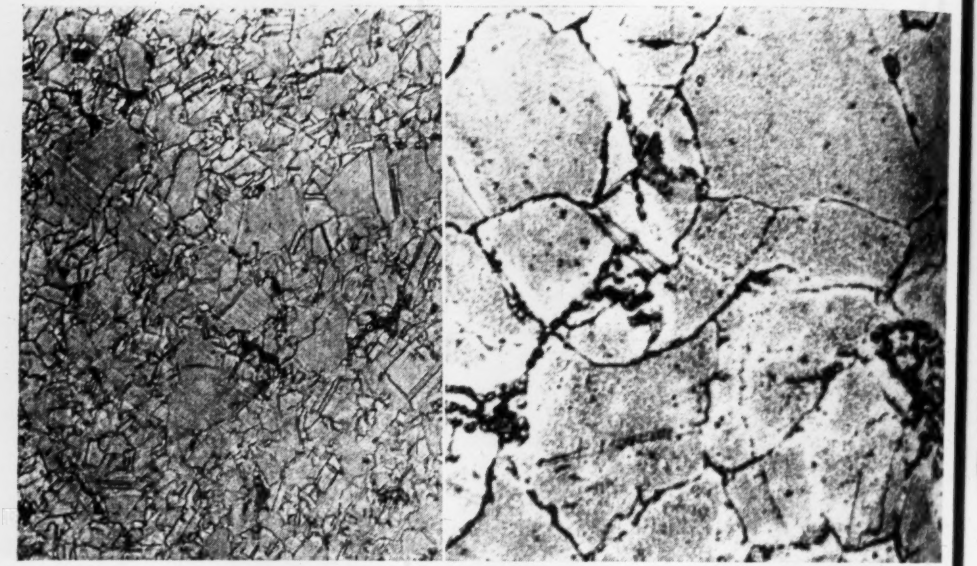

× 100 × 1000

FIG. 9.—Photomicrograph of Material N: N-155.

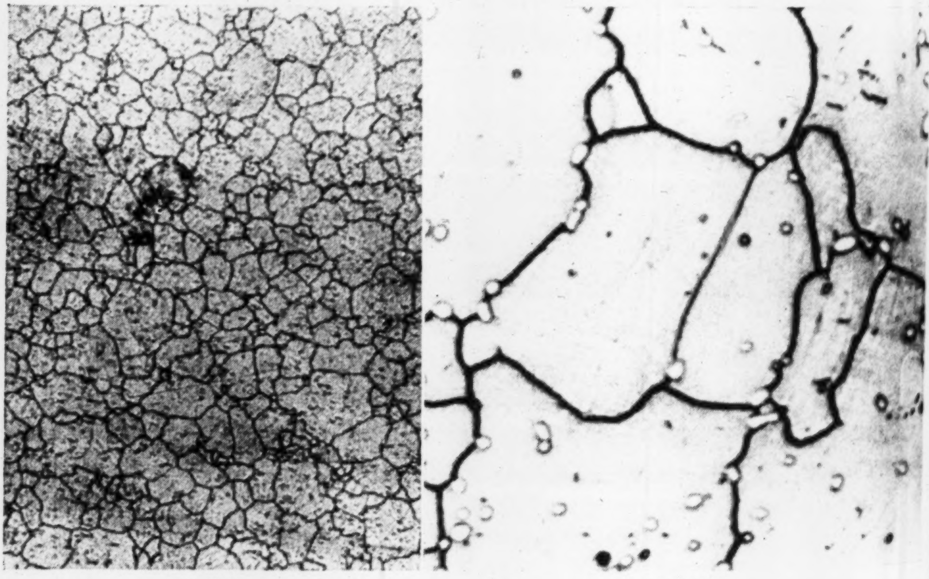

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FIG. 10.—Photomicrograph of Material S: S-816.

near the test section. All metallographic specimens were polished and electrolytically etched in 10 per cent chromic acid.

TEST PROGRAM AND PROCEDURE

Although the machines described under "Testing Equipment" are capable of imposing reversed cyclic stress or

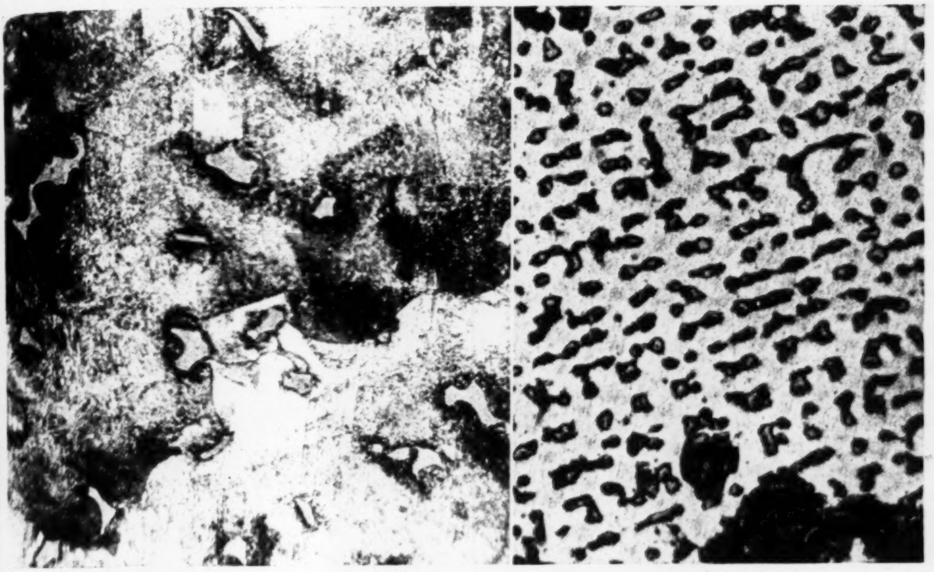

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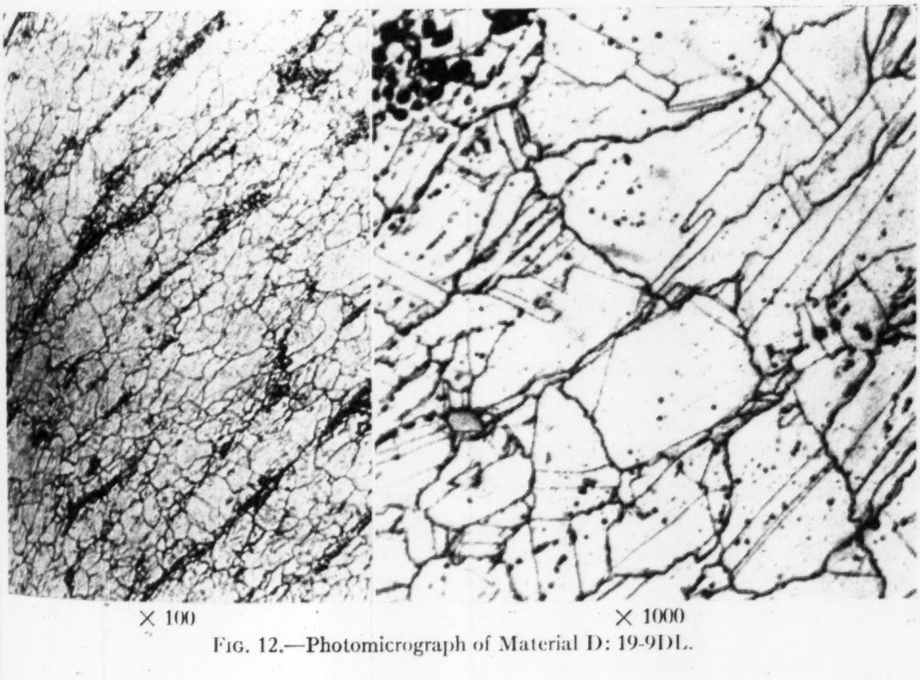
FIG. 11.—Photomicrograph of Material V: Vitallium.



× 100 × 1000

FIG. 12.—Photomicrograph of Material D: 19-9DL.

even unidirectional compressive stress, the specimen grip design is greatly complicated if buckling and eccentricity under compressive load are to be controlled. Therefore, in the interest of simplifying the testing procedure in this first test program, it was decided to confine the work to unidirectional cyclic tensile forces (instantaneous stress *S* in Fig. 1 always on the tension side).

The maximum vibration alternating-mean stress ratio A (see Fig. 1) for the unidirectional tension case is one (cyclic stress from zero stress to maximum tension) and the minimum A value is zero (static stress). It was decided to cover this vibration amplitude-mean stress region by three ratios: $A = 0$, 0.25, and 0.67. Confining all tests to three definite amplitude-mean stress ratios, rather than using the same alternating loads for all mean stresses, or some other similar approach, simplifies the analysis of the data and generally gives a better distribution to the test results. The vibration trough-crest stress ratios (see Fig. 1) which correspond to these three amplitude-mean ratios are $T = 1$ (equivalent to $A = 0$), $T = 0.6$ (equivalent to $A = 0.25$), and $T = 0.2$ (equivalent to $A = 0.67$).

Summarizing the test conditions, each material was tested at each of two temperatures (1350 F. and 1500 F.) under unidirectional dynamic tension having three vibration amplitude-mean stress ratios ($A = 0$, 0.25, and 0.67) and at a fixed cyclic stress frequency (3600 cycles per min. or 5,184,000 cycles per day). The combination of stresses selected for test purposes was generally within the range causing rupture in from 3 hr. to 800 hr.

The standard test procedure is as follows:

1. Apply 1500 psi. static tension to the cold specimen, which stress is maintained during the heating period.
2. Heat specimen to desired temperature, which generally requires approximately 2 hr.
3. After specimen attains its testing temperature, measure location of all specimen targets.
4. One hour after the testing temperature is reached by the specimen, the preload vernier is set to the desired tensile preload (mean stress S_m), starting the preload motor which increases the static tensile stress at the rate of 8400 psi. per min.
5. As soon as the full preload is reached, the preload motor automatically stops, at which time the target positions are again measured.
6. After the specimen has been at full preload for 10 min., the eccentric mass, previously set to produce the desired alternating force, is gradually brought up to speed.
7. Target positions are measured periodically thereafter, using stroboscopic light for the microscope as explained under "Measuring Equipment and Procedures." The dynamic creep so determined is at the instant of peak or crest stress, S_c in Fig. 1.

The total extension at any instant of time can be determined from the target spacing (2-in. effective gage length between targets) at the instant of maximum load minus the target spacing measured in step 3. This extension, therefore, includes the elastic extension between the stress of 1500 psi. and the static preload. However, since this elastic extension is generally very small compared to the total extension, no distinction is made between the total extension as defined above and total creep as used in data and discussions presented later.

TEST RESULTS

The experimental data giving the dynamic creep and rupture properties are presented in the following order for material N-155:

1. A summary table, Table II, which lists all the specimens tested by number and summarizes specimen loading, testing temperature, hours to rupture, per cent elongation, and appropriate notes.

2. A plot in Figs. 13 and 14 of the total creep *versus* time for all specimens, by number, included in Table II. Subsequent plots were made to log-log scale to avoid crowding early stage creep data.

TABLE II.—DATA FOR TEST MATERIAL N: N-155 ALLOY.

Specimen Number	Alternating-Mean Stress Ratio *A*	Applied Stress, psi.			Testing Temperature, deg. Fahr.	Time to Rupture, hr.	Elongation, per cent		Notes
		Mean	Alternating	Maximum			Uncorrected[a]	Corrected[b]	
N 76z	0.66	25.5	16.8	42.3	1350	106	7.2	6.2	*d*
N 73z	0.69	24.0	16.6	40.6	1350	92.9			*d*
N 71z	0.70	30.0	21.0	51.0	1350	26.2	3.0	3.0	Elong. Approx. 1.93 gage
N 75x	0.67	30.0	20.0	50.0	1350	18.2	4.9	4.7	
N 71x	0.64	27.0	17.3	44.3	1350	71.3	3.9	2.7	
N 70y	0.64	24.0	15.3	39.3	1350	445	5.8	5.4	*c*
N 72z	0.65	22.5	14.5	37.0	1350	432	0.7	0.7	*d*
N 66Ebz	0.67	34.5	23.0	57.5	1350	3.7	7.3	5.8	*e*
N 66FBz	0.67	27.0	18.0	45.0	1350	43.3	4.4	2.7	
N 77x	0.67	34.5	23.0	57.5	1350	3.3	8.6	7.0	*e*
N 75y	0.24	38.0	9.0	47.0	1350	14.3	9.5	9.5	
N 73y	0.22	32.0	7.0	39.0	1350	41.2	12.4	11.8	*c*
N 76y	0.25	28.0	7.0	35.0	1350	115.6	8.8	8.6	*c*
N 72y	0.25	24.0	6.0	30.0	1350	651	10.9	9.8	*c*
N 77y	0	40.0	0.0	40.0	1350	10	15.8	15.6	
N 78x	0	30.0	0.0	30.0	1350	106.6	22.0	21.4	
N 74y	0.66	18.0	11.8	29.8	1500	64	4.8	4.5	*c*
N 74z	0.66	21.0	13.8	34.8	1500	50	7.1	6.8	*c*
N 73x	0.65	24.0	15.6	39.6	1500	6.7	9.7	7.7	*c*
N 70z	0.66	18.0	11.8	29.8	1500	139.9	6.1	4.6	*c*
N 76x	0.67	16.5	11.0	27.5	1500	266.7	6.9	6.3	*c*
N 75z	0.25	24.0	6.0	30.0	1500	12.3	16.3	14.2	*c*
N 74x	0.25	20.0	5.1	25.1	1500	73.7	10.3	9.8	*c*
N 70x	0.25	18.0	4.5	22.5	1500	165.2	8.6	6.7	*c*
N 77z	0.25	16.0	4.0	20.0	1500	332.8	3.6	3.4	
N 78z	0	27.5	0	27.5	1500	3.6	20.8	20.5	
N 66Dz	0	20.0	0	20.0	1500	67.9	10.4	9.6	

[a] Uncorrected per cent elongation is determined from measurement of the length of the fractured specimens matched at the fractured section.

[b] Corrected per cent elongation is determined by subtracting from the length measured (footnote *a*, above) the length of the maximum surface opening of the properly matched fractured section. This surface opening correction is intended to eliminate purely localized deformation which occurs after the fracture has started and progressed across most of the specimen. In most cases this correction is quite small.

[c] Effective gage length, determined mathematically (see text), was 2.05-2.12.

[d] Equipment or power failure or other incidents which resulted in stoppage of the test at hours indicated.

[e] Early tests in which there was a 10 to 15 per cent dynamic overstress in the specimen for a fraction of a second during the start of the vibration (see text).

3. Data from table (1) and creep curves (2), above, are plotted in Fig. 15 to show the stress *versus* time for rupture and also stress *versus* time for 2 and 0.5 per cent creep for each of three alternating-mean stress ratios (A = 0, 0.25, and 0.67), and for each of two temperatures (1350 F. and 1500 F.).

4. Data from curve sheet (3) above are replotted within mean stress *versus* alternating stress coordinates in Fig. 16 to give the stress combinations which cause rupture and 2 and 0.5 per cent creep in 10, 50, and 200 hr. at 1350 F. and 1500 F. These summary curve sheets most clearly show the effects of superimposing cyclic stress on a static preload.

Essentially the same plotting procedure was used for S-816, Vitallium, and 19-9DL. However, in the interest of conserving space only the final summary sheets of type (4), above, are shown for these materials in Figs. 17, 18, and

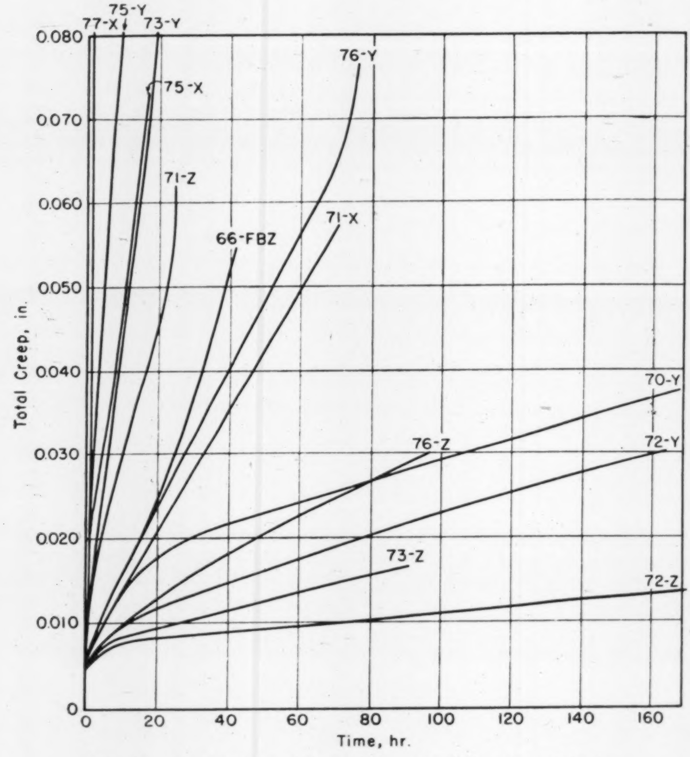


FIG. 13.—Total Creep-Time Curves for N-155 at 1350 F.

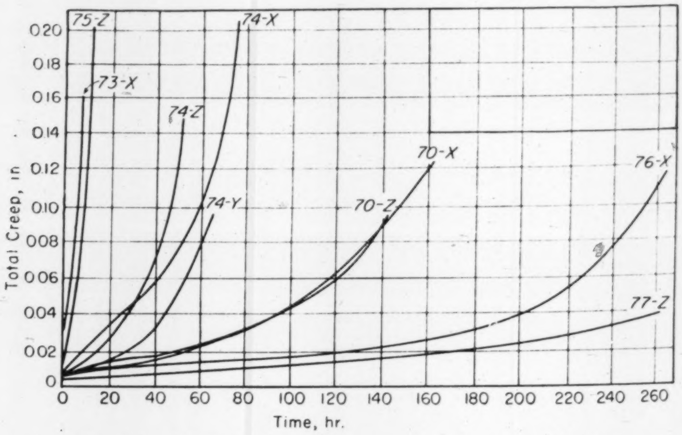


FIG. 14.—Total Creep-Time Curves for N-155 at 1500 F.

19. Some of these curve sheets are incomplete due to insufficient data at the time this report was written.

Since ductility, as indicated by per cent elongation, is an important engineering property, the per cent elongation data are plotted in Fig. 20 as a function of the alternating-mean stress

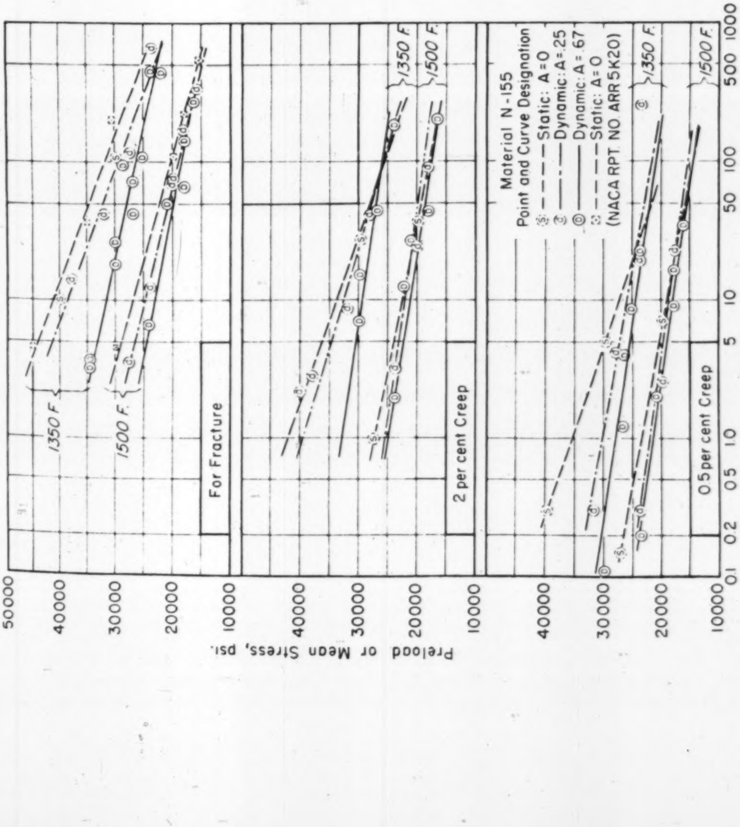


FIG. 15.—Time for Rupture, 2 per cent and 0.5 per cent Creep for Various Combinations of Static and Dynamic Tensile Stress at 1350 F. and 1500 F. for N-155.

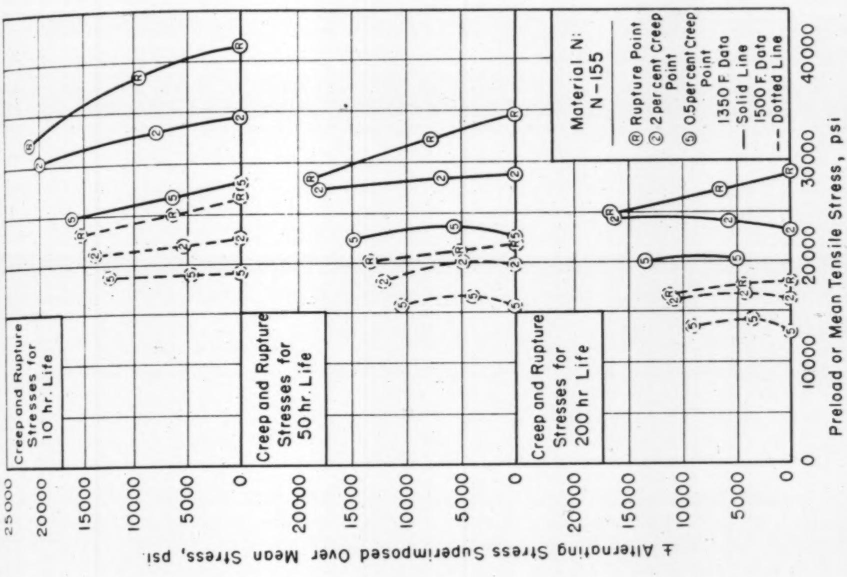


FIG. 16.—Static and Dynamic Tensile Stress Combinations Which Cause Rupture, 2 per cent and 0.5 per cent Creep in 10, 50, and 200 hr. at 1500 F. and 1350 F. for N-155.

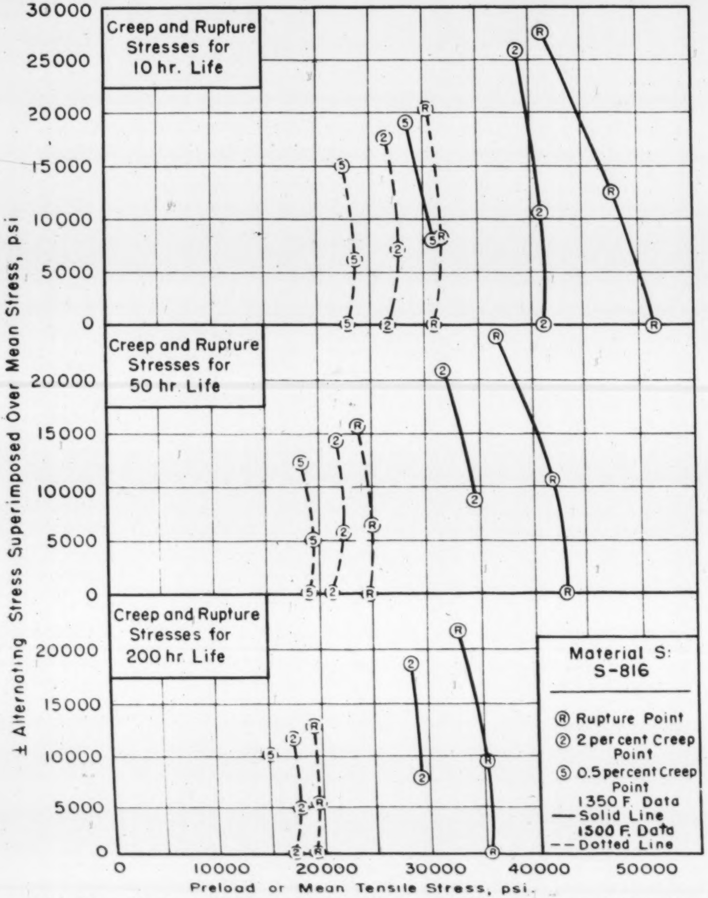


FIG. 17.—Static and Dynamic Tensile Stress Combinations Which Cause Rupture, 2 per cent and 0.5 per cent Creep in 10, 50, and 200 hr. at 1500 F. and 1350 F. for S-816.

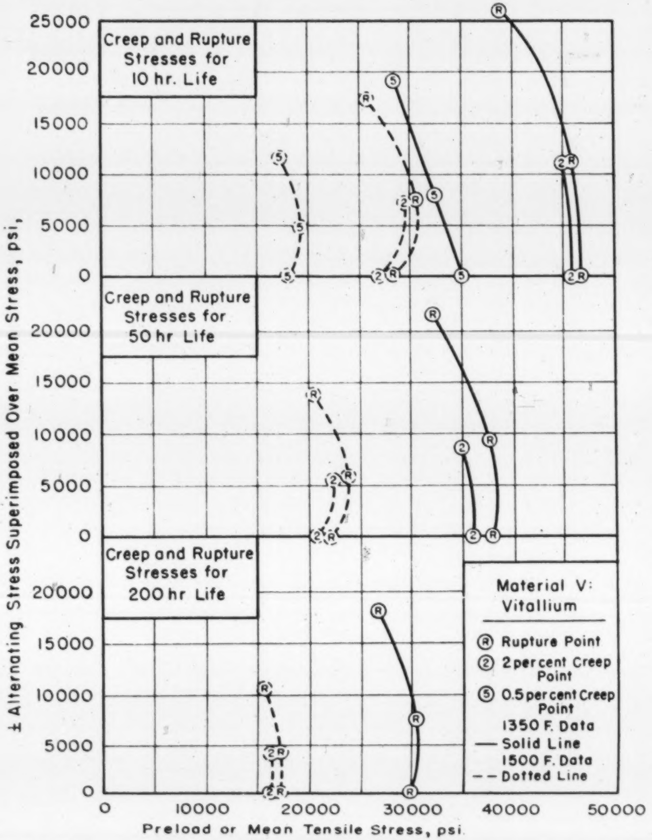


FIG. 18.—Static and Dynamic Tensile Stress Combinations Which Cause Rupture, 2 per cent and 0.5 per cent Creep in 10, 50, and 200 hr. at 1500 F. and 1350 F. for Vitallium.

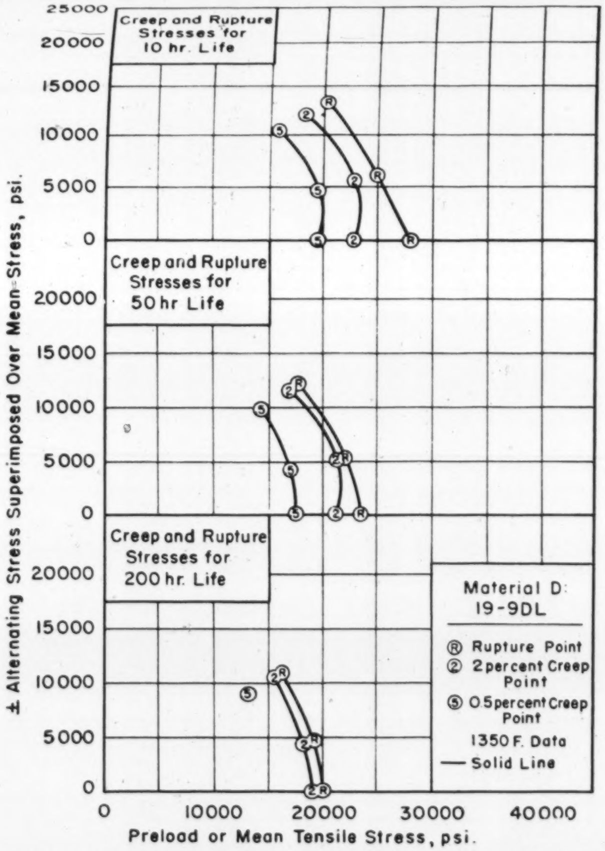


FIG. 19.—Static and Dynamic Tensile Stress Combinations Which Cause Rupture, 2 per cent and 0.5 per cent Creep in 10, 50, and 200 hr. at 1350 F. for 19-9DL.

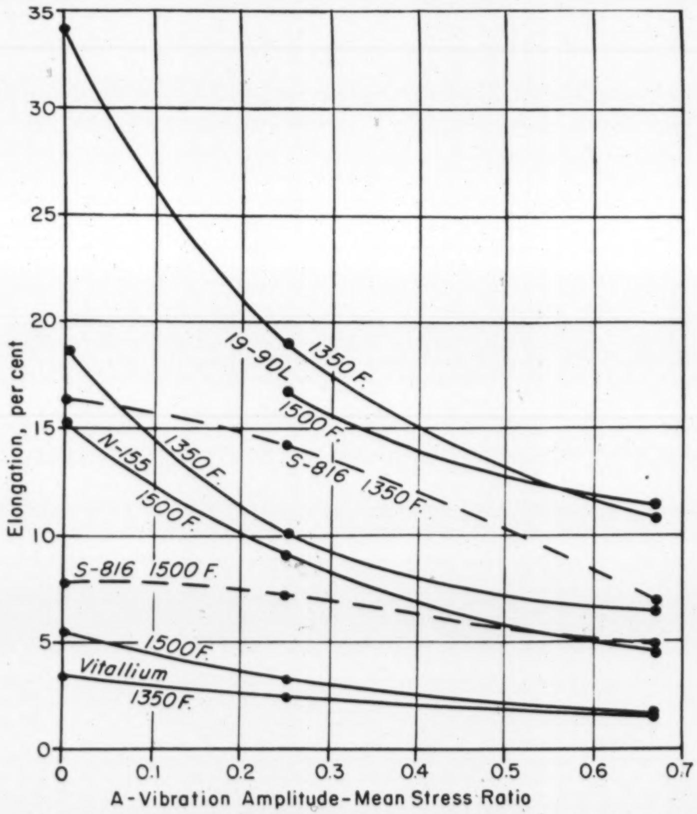


FIG. 20.—Effect of Alternating-Mean Stress Ratio on the Percentage Elongation of Fractured Specimens.

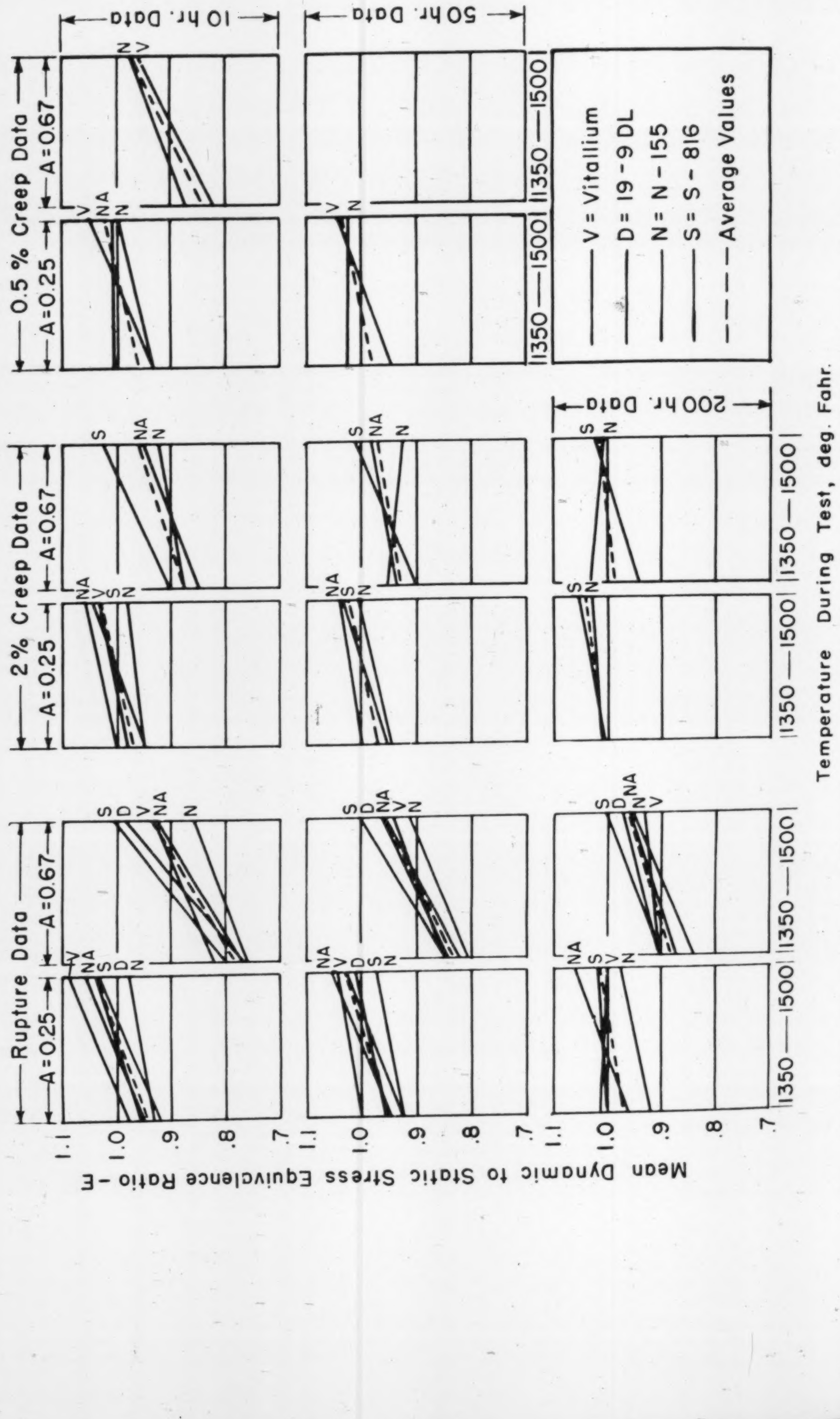


Fig. 21.—Effect of Temperature on Mean Dynamic to Static Stress Equivalence Ratio *E* for Dynamic Creep and Rupture Behavior. Data Shown for Individual Materials.

ratio A. The points shown are the average of both the corrected and uncorrected elongations (see footnotes to Table II for distinction).

DISCUSSION OF RESULTS

Of the several types of data and curve sheets discussed under "Test Results," the summary curves of type (4), showing both the static and dynamic creep and rupture data within the mean stress *versus* alternating stress coordinate system, are the most revealing. These curves show that at 1500 F. the superposition of alternating stress on tensile preload or mean stress does not, in general, greatly affect the time to rupture or creep associated with the same mean stress applied statically (zero alternating stress). At 1350 F., however, cyclic stress has, in general, a more pronounced influence, particularly for high stress levels where time to rupture is relatively short.

In order to demonstrate further the above trends and for purposes of discussion, the mean dynamic to static stress equivalence ratio E is defined as the ratio of the allowable mean stress S_m under dynamic loading to the equivalent static stress S_e which causes the same creep or rupture behavior. Figure 21 shows this mean dynamic to static stress equivalence ratio as a function of temperature and stress ratio A for rupture and 2 and 0.5 per cent creep in 10, 50, and 200 hr. In this curve sheet, data for each test material is shown as solid lines properly identified by letters, and the average of all the four materials discussed in this paper is shown as the dashed line. To facilitate comparison, these average values are replotted in Fig. 22, in which the solid lines represent an alternating-mean stress ratio of 0.67 and the dashed lines give the data for $A = 0.25$. The following discussion is based on values and trends displayed in Fig. 22.

A ratio E of unity means that the addition of alternating stress to a mean preload does not affect the fracture time or creep. If E is larger than one, the addition of cyclic stress actually

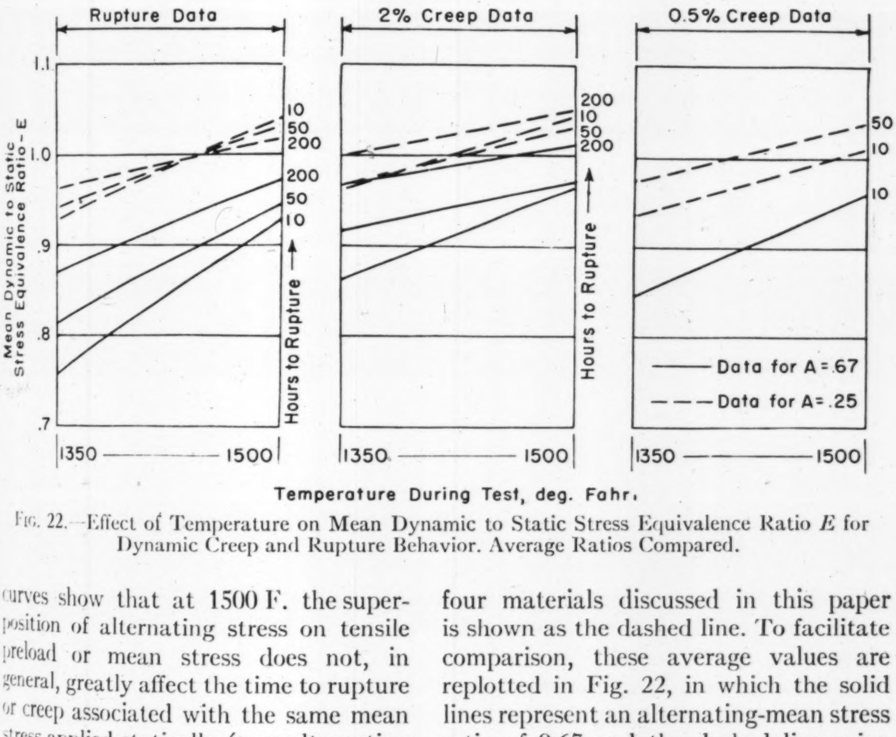


FIG. 22.—Effect of Temperature on Mean Dynamic to Static Stress Equivalence Ratio E for Dynamic Creep and Rupture Behavior. Average Ratios Compared.

increases life or reduces creep; and if E is smaller than unity, cyclic stress accelerates creep or rupture. An unexpected result, shown in Fig. 22, is that all dynamic creep and rupture data at 1500 F. for $A = 0.25$ show average values larger than unity and as high as 1.05. It is indeed surprising that higher allowable stresses are permissible under dynamic conditions than under static forces, and speculatory reasons for this behavior are discussed later. Even for a stress ratio A of 0.67, equivalence ratio E may exceed one at 1500 F.; and the average of creep and rupture data for these four materials has a minimum value of 0.93, a surprisingly high ratio by room temperature standards.

At 1350 F., however, cyclic stress pronouncedly accelerates creep and rupture. Although these trends displaying reduced equivalence ratio E with reduced temperatures are shown over the narrow temperature range of 1500 to 1350 F., this trend in all probability continues downward since at room temperature ratio E for rupture is generally considerable lower than shown in Fig. 22. Summarizing, the importance of cyclic stress as an accelerator of creep and rupture decreases with increasing temperatures, and, in fact, at sufficiently high temperatures, cyclic stress may even decelerate creep and rupture.

At the high alternating-mean stress ratio of 0.67 the equivalence ratio E is smaller for high stress level, short-life tests (say 10-hr. data) than for low stress, long-time tests (say 200-hr. data). The possibility that at high stress levels the internal hysteresis damping of the material caused the temperature of the test section to rise above that of the specimen ends containing the control thermocouple was considered as a possible cause of this behavior. However, no evidence could be found of this temperature difference. Speculations as to possible causes of this trend are discussed later.

The surprisingly small destructive effect of up to 67 per cent alternating stress at 1500 F., and particularly the increase in some cases in allowable mean stress resulting from the superposition of vibrations, is one important result of this work which should receive further study. As a first step towards better understanding of this unexpected behavior, a theoretical analysis is given in the Appendix of the dynamic creep under cyclic stress. In this analysis it is assumed that the instantaneous creep rate is proportional only to a power n of the instantaneous stress. As discussed in the Appendix, this assumption is based on a more fundamental assumption that, (*a*) cyclic stress or, in general, what might be called stress history (8), does not affect the metallurgical structure of the material and its properties differently than static stress, and (*b*) that the instantaneous creep rate is independent of rate of change of stress. That these assumptions are probably unjustified is indicated by the following three observations:

1. The Appendix and Fig. 23 indicate that the equivalent static stress S_e (see previous definition) for A of 0.67 should be closer to the peak dynamic stress S_c than to the mean dynamic stress S_m. For this case the theoretical value of E is approximately 0.72. The experimental observation that S_e is actually much closer to S_m than S_c (E varies between 0.93 and 1.05 at 1500 F.) might indicate either a stress rate effect or that the sustained cyclic stress affects the metallurgical solid state in such a way as to strengthen the material.

2. Metallographic studies now under

way indicate that sustained cyclic stress may accelerate precipitation, aging, and other solid state transformations. An investigation, in which a comparison is made of the final solid state condition of specimens subjected (*a*) to temperature only, (*b*) to static stress and temperature, and (*c*) to dynamic stress and temperature is now under way.

3. Recent work (**8**) indicates that there are continuous changes in damping capacity, an extremely structure-sensitive property, and dynamic modulus of elasticity of materials subjected to high cyclic stress even at room temperatures. Also, sustained cyclic stress accelerates precipitation hardening of aluminum alloys at room temperatures and decreases damping capacity (**9**). In fact, vibratory stress "sufficiently prolonged produces changes in metallurgical conditions normally associated with temperature aging and annealing" (**9**). At elevated temperatures, similar and perhaps more pronounced changes are reasonable in precipitation-hardening alloys such as the temperature-resistant materials under discussion.

In view of the above observations, metallographic and other investigations of the effect of cyclic stress on solid state reactions, precipitation, transformations, and changes in structure will be emphasized in future work. Since such reactions are probably dependent on (*a*) temperature, (*b*) static and cyclic stress history, and (*c*) time, all the trends displayed in Fig. 22 may be explainable after these three fundamental factors have been evaluated.

Dynamic creep and rupture data presented as a function of mean and alternating stress as shown in Figs. 16, 17, 18, and 19, should be of value to design engineers. These curves show that in applications where clearance, etc., is important, dynamic creep considerations may reduce the allowable stress substantially below that indicated solely by rupture considerations, particularly at high temperatures.

In selecting materials for service, the per cent elongation of the ruptured specimen is generally considered important as an indication of ductility. In this connection, the greatly reduced per cent elongation shown in Fig. 20 for the dynamically loaded specimens is significant. The relative ductility rating under static tensile stress may be quite different from that under dynamic tensile stress. In this connection, the flat curve for S-816 at 1500 F. is worthy of notice. Also to be observed is the low elongation (1.7 per cent) of Vitallium at both 1350 F. and 1500 F. for an alternating-mean stress ratio of 0.67.

Although the average per cent elongation data revealed rather consistent trends, as shown in Fig. 20, there is significant deviation in elongation from the average for a given material, temperature, and alternating-mean stress ratio. Attempts to associate this deviation from the mean elongation values with stress level or time to fracture were unsuccessful. Further study of fracture characteristics, now under way, and material variability may reveal the causes of this scatter.

In general, statically loaded specimens show appreciable local yielding preceding fracture, and the reduction in area is generally large. In dynamically loaded specimens, however, the fractures generally occur by progressive growth of minute cracks, and fatigue-type failures with several distinguishable regions result. Fracture studies are now being made to explain these distinguishable regions.

SUMMARY AND CONCLUSIONS

1. The newly developed testing and measuring equipment are well suited

for evaluating the dynamic creep and rupture properties of materials at elevated temperatures. Although the tests reported in this paper were performed under unidirectional tensile fatigue loads, the equipment and newly developed fixtures enable fatigue testing under reversed stress or unidirectional compression.

2. A very satisfactory method of presenting dynamic creep and rupture data is to plot a family of curves within an alternating stress *versus* mean stress coordinate system to show the combinations of dynamic stress which cause (*a*) rupture in N hours and (*b*) M per cent creep in N hours.

3. Such curves show that at 1500 F. the superposition of up to 67 per cent alternating stress on tensile preload does not generally affect the allowable static preload (or mean stress) for a given rupture life or dynamic creep by more than 8 per cent for the materials tested.

4. At 1350 F., however, the presence of 67 per cent alternating stress may reduce the allowable static stress by as much as 25 per cent. In general, the shorter the hours to failure the greater the reduction caused by the superposition of alternating stress.

5. The addition of alternating stress may in many cases even increase the allowable static preload at 1500 F. for a given rupture time or creep; up to 8 per cent increase for 25 per cent alternating load and up to 3 per cent increase for 67 per cent alternating load.

6. The observed increase in allowable mean stress resulting from the addition of alternating stress may be associated with the accelerating effects of vibration on solid state reactions, such as precipitation and age hardening. This promises to be a fruitful field for metallurgical research.

7. Per cent elongation to fracture is pronouncedly reduced by the superposition of alternating stress over static preload. For the materials tested, the average per cent elongation in a dynamic test with 67 per cent alternating stress is reduced to approximately 40 per cent of that caused by static loading. Since different materials are affected differently by dynamic stress (elongation reduction varied from 29 per cent to 63 per cent of the static value), the relative ductility rating of materials under static loading may be significantly different from that under dynamic loading.

Acknowledgments:

This work was sponsored by the Air Materiel Command whose fine cooperation and encouragement are greatly appreciated.

The author gratefully acknowledges the considerable aid of several of his associates. Particularly helpful were Messrs. E. Westberg, A. Yorgiadis, and R. Sells in the conduct and interpretation of the tests, W. Wheadon in the metallographic studies, and G. Gronau for construction of machines and specimens.

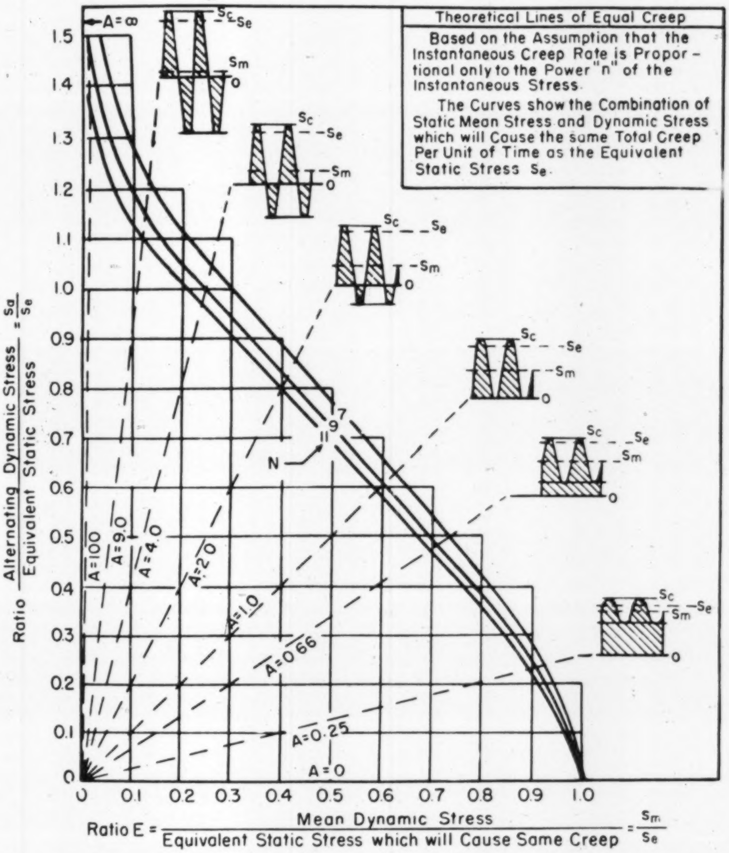
APPENDIX

THEORETICAL RELATIONSHIPS BETWEEN STATIC AND DYNAMIC CREEP

There are three main reasons why the prediction of creep under cyclic stress (dynamic creep) from creep data procured under static loading (static creep) is difficult:

1. *Nonlinear Creep Rate-Stress Magnitude Relationship.*—Creep rate is not generally linearly proportional to stress, but rather proportional to some power or other function of stress. The addition of cyclic stress should, therefore, generally result in creep larger than that associated with the mean load applied statically.

2. *Dependence of Instantaneous Creep Rate on Rate of Change of Stress.*—The inelastic behavior of materials is frequently dependent on the rate of increase of stress (**11**). The variable rate of stress increase and decrease during cyclic stress must therefore be considered.



Theoretical Lines of Equal Creep

Based on the Assumption that the Instantaneous Creep Rate is Proportional only to the Power "n" of the Instantaneous Stress.

The Curves show the Combination of Static Mean Stress and Dynamic Stress which will Cause the same Total Creep Per Unit of Time as the Equivalent Static Stress S_e.

FIG. 23.—Theoretical Curves Showing the Effect of Alternating Stress on Creep, Assuming Negligible Stress History Effect.

3. *Stress History Factor.*—The cyclic stress history imposed during a dynamic creep test may affect the *long term* metallurgical change caused by stress history or the *short term* behavior during the stress cycle or soon thereafter. These two types of stress history effects are discussed below:

(*a*) Over prolonged periods of time, cyclic stress may accelerate precipitation, aging, and other solid state metallurgical transformations or it may cause slip or other forms of lattice distortions different from that caused by static effects. There is some evidence that this factor may be one of considerable importance.

(*b*) During a stress cycle such short-term factors as the "memory" effects, hysteresis loop, other inelastic behaviors, changed facility for lattice slip and distortion, etc., may cause the instantaneous creep rate at a given stress level to be different during a stress cycle than during a sustained static stress or a uniformly increasing stress.

Although a study is now under way on the stress history factor (3), its analysis will not be attempted at this time. Little is known also about the stress rate factor (2).

Consequently, only the nonlinear creep rate factor (1) is considered in this analysis. It is recognized that due to the omission of factors (2) and (3), large differences can be expected between the theoretical values determined below and experimental data. However, such an oversimplified analysis is a necessary first step and will aid in establishing trends and reasons for observed behaviors. It is therefore assumed in the following analysis that the creep rate depends only on the magnitude of the instantaneous stress and is independent of previous stress history or stress rate. Thus, in addition to the limitations mentioned above, the results obtained apply only to the second stage (linear-with-time region) of creep.

The static creep rate *versus* stress magnitude relationships for the temperature-resistant alloys under consideration were determined from previous work (5). Since the log-log plots of these data result in reasonably straight lines, it may be assumed that the creep rate is proportional to some power of stress magnitude. Thus:

TABLE III

Vibration Ratio A	Values of E		$\frac{S_e}{S_m}$	$\frac{S_c}{S_e}$
	$n = 7$	$n = 11$		
0	1.000	1.000	1.00	1.00
0.25	0.938	0.908	1.08-1.10	1.16-1.12
0.67	0.736	0.698	1.32-1.43	1.23-1.16
1.00	0.624	0.586	1.60-1.70	1.25-1.17
2.00	0.426	0.399	2.34-2.52	1.27-1.19
4.00	0.260	0.241	3.85-4.15	1.30-1.20
9.00	0.135	0.122	7.42-8.22	1.35-1.21

$$C = KS^n \qquad \text{(2)}$$

where:

C = creep rate in inches per inch per hour,

K = a proportionality constant,

S = stress magnitude in pounds per square inch, and

n = the power or exponent determined from the slope of the log-log plots of minimum creep rate (linear portion of creep-time curves) *versus* stress magnitude.

The static creep data available indicates that the exponent n varies between 7 and 11, depending on the material, its treatment, and the test temperature.

During a cyclic stress test, the instantaneous stress S at any instant of time may be defined as:

$$S = S_m + S_a \sin ft = S_m(1 + A \sin ft) \qquad \text{(3)}$$

The terms used in the above equation are defined in Fig. 1. Combining Eqs. 2 and 3:

$$C = KS_m^n(1 + A \sin ft)^n \qquad \text{(4)}$$

The total creep in a time interval t_1 to t_2 is, therefore:

$$\text{Total Creep}\Big]_{t_1}^{t_2} = \int_{t_1}^{t_2} C\,dt \qquad \text{(5)}$$

$$= KS_m^n \int_{t_1}^{t_2} (1 + A \sin ft)^n\,dt$$

It is desirable to determine the equivalent static stress S_e which will cause the same total second stage creep in a given interval of time as the dynamic stress ($S_m \pm S_a \sin ft$). Let the ratio $\frac{S_m}{S_e}$ be defined as the mean dynamic to static stress equivalence ratio E. Therefore:

$$\text{Total Creep}\Big]_{t_1}^{t_2} = \int_{t_1}^{t_2} KS_e^n\,dt = KS_e^n(t_2 - t_1)$$

$$= KS_m^n(t_2 - t_1)/E^n \qquad \text{(6)}$$

Combining Eqs. 5 and 6:

$$E = \left[\frac{t_2 - t_1}{\int_{t_1}^{t_2} (1 + A \sin ft)^n\,dt}\right]^{1/n} \qquad \text{(7)}$$

Since there appears to be no simple analytical solution for the above integral, graphical integration methods were used. In this analysis the values of n considered are 7, 9, and 11 and the values of A considered are 0.25, 0.67, 1.00, 2, 4, and 9. Table III gives the calculated values of E for the above mentioned values of n and A.

The calculated data given in Table III are plotted in Fig. 23 to show the theoretical relationships between static and dynamic stress for equal second stage creep. The three curves shown connect static stress and dynamic stress combinations which will theoretically cause the same total creep per interval of time. If, for example, the creep rate of a certain material at a certain temperature is a ninth power function of stress magnitude, then a dynamic stress of 0.13 ± 1.14 S_e should cause the same total creep as a dynamic stress of 0.6 ± 0.6 S_e, which in turn should cause the same total creep as a static stress of 1.0 ± 0. S_e.

Also indicated in Table III and shown to scale in Fig. 23 are the mean stress S_m and equivalent static stress S_e for cyclic stress of various amplitude-mean stress ratios A. One interesting trend is the increasingly larger difference between S_e and S_m as A increases. In fact the value of S_e is closer to crest stress value S_c than mean stress value S_m in most cases, the higher the exponent n the closer S_e approaches S_c. Another interesting trend, even though expected, is the larger the ratio A the higher is the crest value S_c the specimen can withstand without exceeding a specified total creep. Of course, in the region of A greater than approximately 1.00, the allowable stresses are limited more by rupture under dynamic stress (or fatigue failure) than by dynamic creep.

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[See Joint Discussion, page 799.]

EFFECT OF PULSATING LOADS ON THE CREEP CHARACTERISTICS OF ALUMINUM ALLOY 14S-T*

By M. J. Manjoine[1]

Synopsis

This paper describes a creep-rupture testing machine in which oscillating and steady loads may be applied. This machine was developed to check the influence of adding a small oscillating stress to the steady stress in a creep-rupture test. The results of a series of tests at 400 F of 14S-T aluminum alloy specimens under an oscillating stress of 10 per cent of the mean stress are reported. The effect of this oscillating stress depends on the magnitude of the mean stress. A possible explanation of the test results is discussed.

In the design of parts for turbines and compressors, the nature of the applied stress must be considered. Because of the high speed of rotation many of the parts are subjected to a steady centrifugal load. A vibratory or oscillating load is added to some of these parts since the impulses from the nozzles to the rotating blades are intermittent. These machine parts, under this type of combined stress, have been designed by assuming that either the mean of the vibratory stress is the dominant one or by making some assumption as to the manner in which the oscillating and mean stresses may be combined. The purpose of this paper is to describe a pulsating load creep-rupture machine and to report the results of a series of tests leading toward the objective of checking the validity of one of the present methods of combining oscillating and steady stresses.

The tests reported herein are constant load and pulsating load creep-rupture tests of a 14S-T aluminum alloy at 400 F. Additional pulsating-load or range-of-stress tests and endurance tests are planned as part of a long-range program.

Material

The material from which the specimens were machined was a 14S-T aluminum alloy disk. The disk was hand forged from an eight inch round billet, solution treated at 940 F. for 3 hr. and then water quenched. The specimens were cut from the disk as shown in Fig. 1 and machined according to the sketch in Fig. 2. They were then aged at 340 F. for 8 hr. The chemical analysis of the disk is as follows:

Copper, per cent	4.00
Iron, per cent	0.35
Aluminum, per cent	93.37
Manganese, per cent	0.69
Silicon, per cent	1.15
Magnesium, per cent	0.44
Chromium, per cent	trace

Testing Machine and Calibration

The pulsating-load creep-rupture machine, Fig. 3, is similar to the screw-driven creep-rupture machine which has been described in a previous paper (**1**).[2]

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] Research Engineer, Mechanics Dept., Westinghouse Research Laboratories, East Pittsburgh, Pa.

[2] The boldface numbers in parentheses refer to the list of references appended to the paper, see p. 798.

In the screw-driven machine, the load is applied through the deflection of a spring. This machine has been altered by adding a loading arm, *A*, Fig. 3, to apply the pulsating load. This arm is a "10 to 1" lever in which the long arm is cut into three segments. The outer segments, joined at the end, carry the steady load to the spring, *B*. The oscillating load is applied through the central segment of the arm by a rotating adjustable eccentric, *C*, shown at the rear of the machine on the right. The frequency of the pulsations can be varied from 3 to 30 cycles per sec. by the variable speed belt drive, *D*. Lower frequencies can be obtained by using the speed reducer adjacent to the variable speed drive. The loads are measured and maintained through the use of the dial gages, *E*, and the associated electronic circuits. The specimen, *F*, can be surrounded and heated by the furnace, *G*. The recorder, *H*, plots a continuous record of the strain *versus* time. The motor and furnace controls are mounted in the panel, *I*, on the left side of the machine. The machine has a capacity of 10,000 lb. for steady loads and ±1000 lb. for oscillating loads.

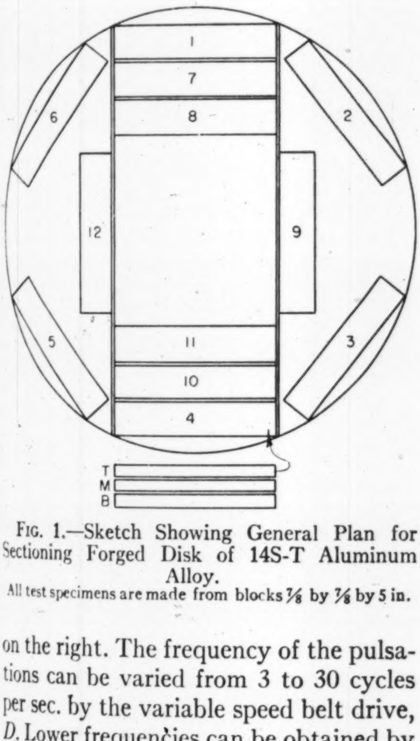

FIG. 1.—Sketch Showing General Plan for Sectioning Forged Disk of 14S-T Aluminum Alloy.
All test specimens are made from blocks ⅞ by ⅞ by 5 in.

The loading springs and indicating dial gages are calibrated both statically and dynamically. A dummy specimen of the same material as that to be tested is used in the calibration. This specimen, on which resistance strain gages are mounted, and the spring, *B*, are calibrated statically as force dynamometers by placing the dummy specimen in the machine in series with a tension dynamometer. The dummy specimen is then assembled in the machine without the tension dynamometer in the same manner as a specimen to be tested and the static calibration is completed. In this calibration the changes in the loads on the specimen and the loading spring are measured at several mean loads for various eccentric travels. The dynamic calibration is finally made by repeating this latter calibration at 2 and 20 cycles per sec.

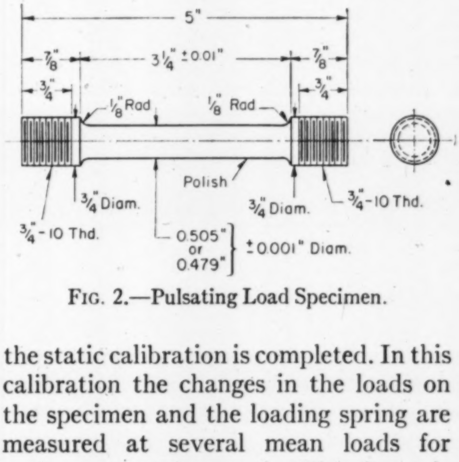

FIG. 2.—Pulsating Load Specimen.

TEST PROCEDURE

After assembly into the machine, the specimen is brought to temperature and held several hours before loading. The distribution of the heat in the furnace is adjusted until the top, middle, and bottom temperatures are within one to two degrees Fahrenheit of the test temperature. The steady load is applied by driving the upper crosshead by the screw jack *J* (Fig. 3). The load is measured by the dial gage on the calibrated spring *B*. The oscillating load is then applied by attaching and starting the eccentric drive, the amount of eccentricity having previously been set. These tests were made with an oscillating load of ± 10 per cent of the steady load and at a frequency of 20 cycles per sec. The loading motor controls are set to maintain the maximum load in the cycle constant and, therefore, the mean load is constant. The recorder is connected and the creep-time curve is drawn autographically. The maximum and minimum of the load can be checked during the tests by the dial gages, *E* (Fig. 3). At rupture the machine shuts off automatically. For the constant load tests the eccentric arm is disconnected.

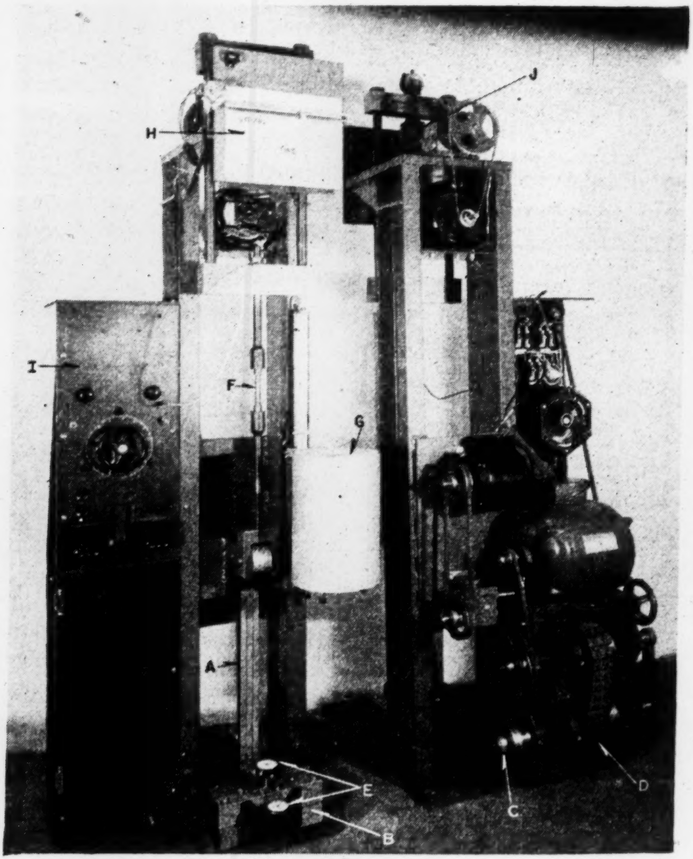

FIG. 3.—Pulsating Load Creep-Rupture Machine.
Two machines, front and back views.

TEST DATA

Pulsating-load and constant-load creep-rupture tests were made at 400 F. on specimens of this 14S-T aluminum alloy disk. The results of these tests are given in Table I. The specimen number indicates the position in the disk from which the specimen was cut (Fig. 1). The letter following the number denotes from which layer of the disk the specimen was obtained. The "stress" is the load stress based on the original cross-sectional area.

For the pulsating-load tests, the mean stress is given. The "intercept" is the intercept in per cent of plastic strain on the strain ordinate of the tangent to the creep curve at the minimum creep rate. "Creep rate" is the minimum creep rate during the creep-rupture test expressed in inches per inch per hour. The "transition point" of these curves is the transition from the second to third stages of creep arbitrarily taken as that point where the creep rate has increased 10 per cent above the minimum creep rate. The Vickers pyramid hardness is taken on

TABLE I.—RESULTS OF PULSATING LOAD AND CONSTANT LOAD CREEP-RUPTURE TESTS OF 14S-T ALUMINUM ALLOY AT 400 F.

Specimen	Stress, psi.	Intercept Strain,[a] per cent	Creep Rate, in. per inch per hr.	Transition Point		Rupture		Vickers Diamond Pyramid Hardness, 20-kg. Load		Reduction of Area, per cent
				Time, hr.	Strain, per cent	Time, hr.	Strain, per cent	As Rec.	After Test No Stress	
PULSATING LOAD TEST[b]										
No. 2B	30 000	0.13	1.3×10^{-4}	20+	0.42+	[c]		177	135	22.6
No. 2M	25 000	0.17	4.6×10^{-5}	100+	0.63+	[c]		166	121	
No. 2T	22 000	0.08	1.8×10^{-5}	135	0.34	211	89.2	166	101	61.0
No. 8T	25 000[d]	0.07	3.7×10^{-5}	49+	0.27+	[c]		171	119	
No. 8B	20 200	0.06	1.5×10^{-5}	210+	0.37+	[c]		165	108	
No. 11M	30 000[e]	0.11	1.48×10^{-4}	15	0.37	29	3.90	160	131	22.6
No. 9B	27 800[e]	0.10	1.45×10^{-4}	26	0.52	39.2	4.21	166	122	32.3
No. 11T	23 000[e]	0.09	2.71×10^{-5}	125	0.46	159	5.01	163	110	46.0
CONSTANT LOAD CREEP-RUPTURE TESTS										
No. 4B	21 000	0.05	2.1×10^{-5}	51+	0.15+	[f]		169	82.1	
No. 5T	21 000	0.08	2.2×10^{-5}	170	0.48	224	8.1	177	103	64.2
No. 4M	25 000	0.08	4.4×10^{-5}	37+	0.24+	40+[g]	8.9	168	120	57.6
No. 5B	26 000	0.10	4.7×10^{-5}	69	0.50	90	3.82	169	125	33.6
No. 5M	28 000	0.10	6.7×10^{-5}	48	0.45	65.5	3.36	164	122	27.0

[a] All strains given are plastic strains.
[b] Oscillating stress ±10 per cent of mean stress at 20 cycles per sec.
[c] Broke in threads.
[d] Oscillating stress ±13 per cent for this test only.
[e] Diameter 0.479 in., others 0.505 in.
[f] Specimen over heated at 51 hr. to 440 F. for 24 hr.—test stopped.
[g] Specimen over heated to 420 F. at 37 hr., broke at 40 hr.

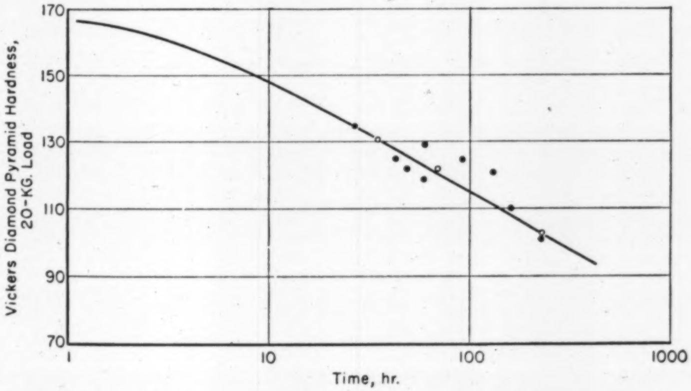

FIG. 4.—Annealing for 14S-T Aluminum Alloy at 400 F. (At No Stress).

the ends of the specimen where no stress acts. A plus sign following a given value in the table indicates that the test was disturbed or interrupted before the actual point was reached. Any exceptions or comments are explained in the footnotes.

TEST RESULTS

The first three pulsating load tests were made on specimens cut from position "2" of the disk. Since there may be some variation in the properties of the specimens cut from various parts of the disk, it was felt that these specimens would be as nearly indentical as possible. The specimen at a mean stress of 22,000 psi. broke normally, but the ones at the higher mean stresses broke in the threads. This fracture in the threads shows that this alloy is notch sensitive under the action of pulsating loads. The notch sensitivity apparently decreased in the test at the mean stress of 22,000 psi. One reason for this decrease is the annealing at 400 F. of this alloy, as shown in Fig. 4. These data are taken from Table I. Another is the stress relieving due to plastic flow in the base of the threads which has time to take place in the longer test. Two other pulsating load tests were made on specimens cut from position "8" of the disk. These specimens were altered by machining a larger radius at the root of the threads. As the specimens had previously been machined the same as the ones above, these latter specimens were slightly smaller in diameter at the root of the threads. One of the specimens was tested at a stress of 25,000 psi. and the other at a lower stress of 20,200 psi. Both broke in the threads. The latter test is not strictly comparable with the other tests since the oscillating load was ±13 per cent. This resulted from an error in setting the eccentric. The results are included since the test is not too different from the other.

All the above specimens were machined as shown in Fig. 2 and with a gage diameter of 0.505 in. Three additional specimens, cut from similar positions in the disk, were altered by reducing the gage diameter to 0.479 in. (10 per cent reduction of area). These specimens were tested at mean stresses of 30,000, 27,800, and 23,000 psi. All these specimens broke in the gage length.

The creep-rupture curves for the pulsating load tests are reproduced in Fig. 5. At stresses for which two tests are reported in Table I, the curve for only one of them is reproduced. The rupture time and strain are given adjacent to the curves which would extend beyond the curve sheet. These curves show that the strain at rupture increases as the mean stress is decreased and the rupture time increases. The strain at the transition point, however, indicates no regular change but is about 0.5 per cent or less for all the tests.

The creep-rupture curves for the constant load tests, Fig. 6, are very similar to those in Fig. 5 and, in general, show the same effect in the transition and rupture strains.

No points are shown in Figs. 5 and 6 since they are replots of continuously recorded curves.

The results of these two types of tests are summarized in Fig. 7. The minimum creep rate and rupture curves are shown for both the constant-load and pulsating-load tests. The transition-point curve is given only for the latter tests. The corresponding plastic strain is given adjacent to the test point. For the stresses used in these tests these curves are practically straight lines in this semi-log plot. Results of other tests have shown that these curves bend over at the ends toward the horizontal for higher and lower stresses. The interesting result of these tests is that the slopes of the curves for the pulsating-load tests seem to be different from those of the constant load tests. The rupture strength under a 10 per cent pulsating load is poorer than for

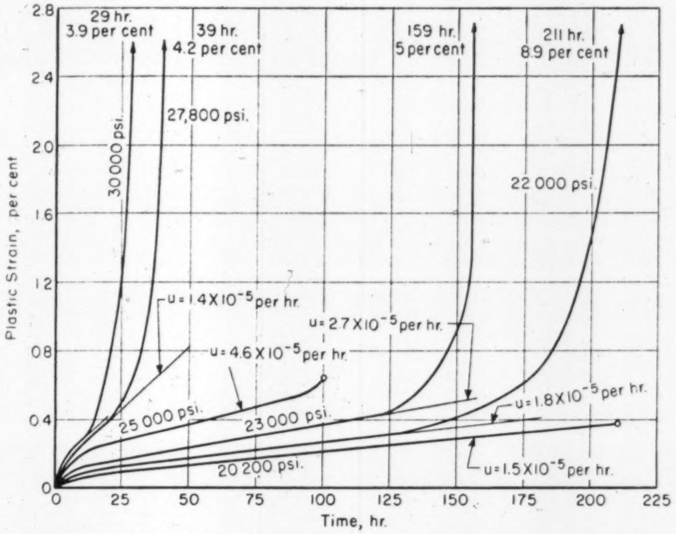

FIG. 5.—Pulsating Load Creep Rupture Curves for 14S-T Aluminum Alloy Disk at 400 F.

The circle at the end of the curves mean the specimen failed in the thread. (Oscillating Stress = 10 per cent of Mean Stress at 20 Cycles per second.)

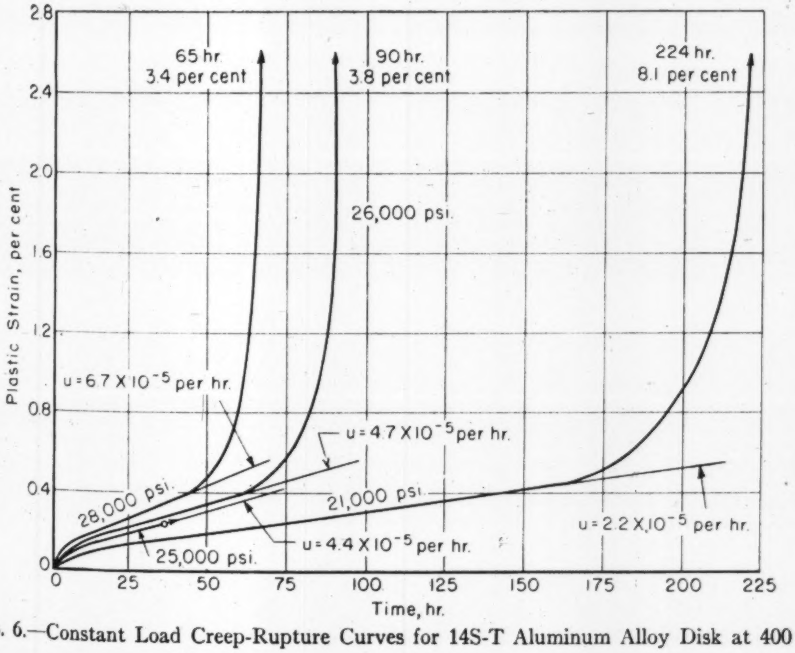

FIG. 6.—Constant Load Creep-Rupture Curves for 14S-T Aluminum Alloy Disk at 400 F.

that under a constant load up to 200 hr. but is greater for a longer rupture time. The same is true of the creep strength for creep rates above and below that of 4×10^{-5} per hr. Since the characteristic shape of these rate curves is like a flat "S", it is thought that the curves will not continue to diverge if investigated over a wider range.

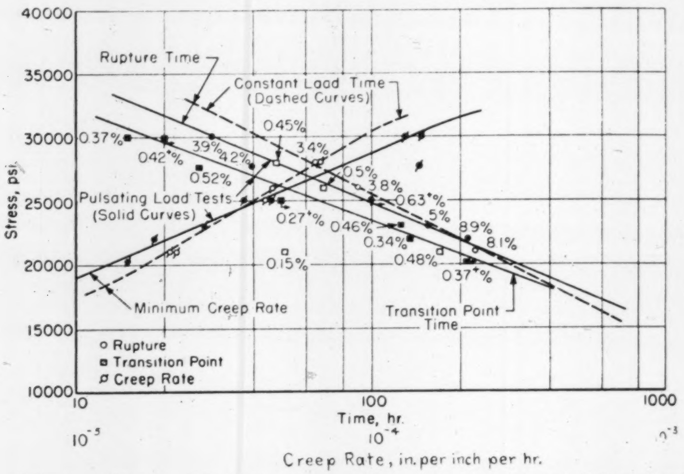

FIG. 7.—Creep-Rupture Tests under Pulsating and Constant Loads of 14S-T Aluminum Alloy Disk at 400 F.

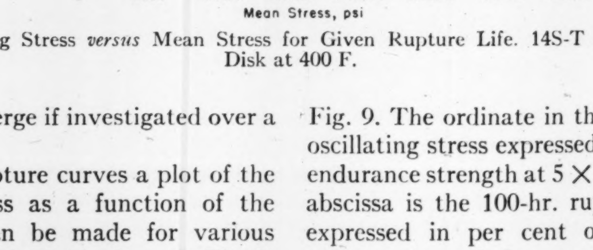

FIG. 8.—Oscillating Stress *versus* Mean Stress for Given Rupture Life. 14S-T Aluminum Alloy Disk at 400 F.

From the rupture curves a plot of the oscillating stress as a function of the mean stress can be made for various rupture lives. This plot is shown in Fig. 8. The points are given for 300, 100, and 30 hr. The shape of the curves is a function of the rupture life because of the crossing of the rupture curves as shown in Fig. 7. Additional tests with greater oscillating stresses and endurance tests are planned for this material to complete these curves.

One method of combining these stresses for design purposes is given in Fig. 9. The ordinate in this curve is the oscillating stress expressed in per cent of endurance strength at 5×10^8 cycles; the abscissa is the 100-hr. rupture strength expressed in per cent of the 100-hr. rupture strength for constant load. The curve proposed for design is an arc of a circle passing through the "100 per cent points," the rupture strength being chosen for the particular life desired. The result of the tests reported herein is plotted as an open circle to show how nearly it conforms to this curve. Since no data were available on the endurance strength of a 14S-T material with a similar history, the endurance strength was estimated for this plot from the results of other 14S-T tests to be about 12,500 psi.

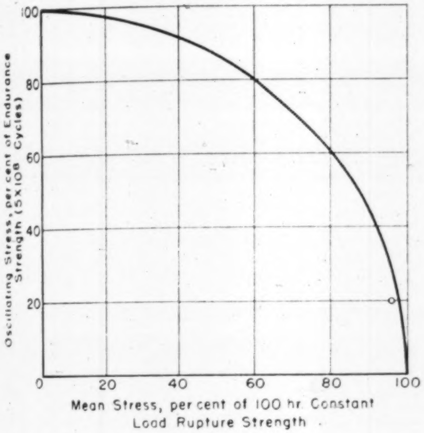

FIG. 9.—Combined Oscillating and Mean Stresses.

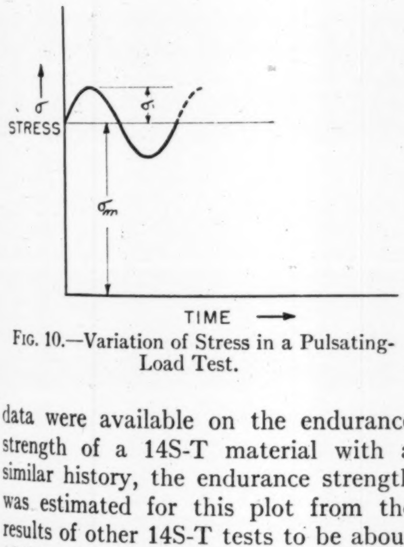

FIG. 10.—Variation of Stress in a Pulsating-Load Test.

DISCUSSION

To explain the above results it will be necessary to review some of the factors which influence the rate of strain and fracture. The manner in which the stress varies during the pulsating-load test is given in Fig. 10 where "σ_m" is the mean stress and "σ_1" the oscillating stress. In these tests σ_1 is 10 per cent of σ_m and the frequency of the oscillation is 20 cycles per sec. The stress, therefore, can be expressed as:

$$\sigma = \sigma_m + \sigma_1 \sin \omega t$$

From the work of other investigators (2, 3) and from these test results for stresses below about 29,000 psi. the creep rate for constant load can possibly be expressed by

$$u = u_0 \sinh \left(\frac{\sigma}{\sigma_0} \right)$$

in which u is the creep rate and σ the applied stress; u_0 and σ_0 are constants.

If we assume that the frequency of the oscillations is low, then we can expect that this relation will give the change in creep rate which will occur in a pulsating load test. The average creep rate over the cycle is given as:

$$u_p = \frac{1}{2\pi} \int_0^{2\pi} u_0 \sinh \left(\frac{\sigma_m + \sigma_1 \sin \theta}{\sigma_0} \right) d\theta$$

where u_p is the average creep rate in the pulsating load test.

For a constant load test at the mean stress the creep rate is expressed by:

$$u_c = u_0 \sinh \frac{\sigma_m}{\sigma_0}$$

The ratio of these creep rates is, therefore:

$$\frac{u_p}{u_c} = \frac{\frac{1}{2\pi} \int_0^{2\pi} \sinh \left(\frac{\sigma_m + \sigma_1 \sin \theta}{\sigma_0} \right) d\theta}{\sinh \frac{\sigma_m}{\sigma_0}}$$

which reduces to

$$\frac{u_p}{u_c} = \frac{1}{2\pi}\int_0^{2\pi} \cosh\frac{\sigma_1 \sin\theta}{\sigma_0}\, d\theta = J_0\left(i\frac{\sigma_1}{\sigma_0}\right)$$

where $J_0\left(i\frac{\sigma_1}{\sigma_0}\right)$ is a Bessel Function of zero order. This ratio has been computed for our 14S-T aluminum alloy disk for a 10 per cent oscillating stress and the results are as follows: at a mean stress of 30,000 psi. the increase in average rate is 6.4 per cent; at 18,000 psi. the increase is only 2.3 per cent. An inspection of Fig. 7 indicates that the creep rate for the pulsating load test is greater than that for the constant load test at 30,000 psi. and that the creep rate curves converge as the stress is decreased. However, the differences that can be noted are that the increase in creep rate at 30,000 psi. is about 50 per cent and that the creep rate curves cross at about 25,000 psi. Since the creep rate curve bends over at the higher stresses a greater average creep rate can be expected than that predicted by using the hyperbolic sine curve which is practically a straight line in this range of stress.

In the above analysis it was assumed that the frequency of pulsations was low. If the frequency is increased to 20 cycles or more per second, then it is expected that this higher rate of loading will result in a higher strength. A tension test was made on a specimen of this alloy from another disk at a rate of loading which was about equal to the average rate from minimum to maximum in the oscillating load of 20 cycles per sec. The 0.2 per cent yield stress was 40,000 psi. at 400 F. This effect has also been demonstrated in tests by Davis (4) and is similar to the increase in stress for increased rates of straining for pure aluminum as reported by the author in a previous paper (5). On the other hand at 400 F. the mean stresses used in these tests are greater than the endurance limit of this alloy for 5×10^8 cycles, so that if an oscillating load is applied, then the same mechanism which causes failure in a fatigue test will influence the failure or rate of strain in the pulsating load test. The fractures in the threads of the specimens which were described earlier indicate that this 14S-T alloy is notch sensitive. The data in Table I show that the ductility is low at 400 F. if the specimen is not heated for a long period. Also described was the observation that the fracture in the threads could be stopped by reducing the area of the gage length by 10 per cent.

The following analysis is offered to help explain the test results obtained. Yielding occurs as a progression of microscopic regions of plastic flow. That is, some region, grain or crystal, which is weakened by a minute imperfection, less favorable orientation or small impurity, will yield under an applied load. This may relieve the stress raiser at that point but will cause a stress concentration on neighboring regions and the flow will proceed throughout the volume. The magnitude of the stress to produce yielding is a function of rate of loading, as mentioned above, but the higher the stress the greater will be the number of regions in which yielding will proceed. The magnitude of the strain, therefore, depends on the duration of the stress, rate of local flow and number of regions which are yielding. The rate of flow, once yielding has been initiated, is also a function of the applied stress. The applied load will be assumed to be a steady load of a magnitude equal to the minimum load (mean load less 10 per cent) and a combined oscillating load which has a "sawtooth" wave shape. The amplitude of oscillating load is 20 per cent of the mean load, and the loading rate is equal to the "effective rate" obtained in the oscillating load of 20 cycles per sec.

Plastic flow in the specimen will be assumed to be made of two parts: a first part caused by the minimum load which is a function of the stress at the minimum load only and a second part which is a result of the oscillating load. Under this latter or "additional" part it will be assumed that, because of the rapid rate of loading, no flow will take place unless a stress of 40,000 psi. is reached and that at this stress the rate of flow will be about 100 per cent per hr. From the point where the two creep-rate curves cross in Fig. 7, the magnitude of the stress concentration can be found to satisfy the above assumptions. This concentration factor is such that at the maximum of the oscillating load the stress will be slightly greater than 40,000 psi., that is, it must be about 1.5. From the above assumptions additional flow will take place whenever the maximum stress is greater than 40,000 psi. divided by 1.5 (26,700 psi.). In a pulsating load test at a mean stress of 30,000 psi. the minimum stress is 27,000 psi. and the maximum stress is 33,000 psi. Additional flow will, therefore, occur throughout the oscillating load cycle and the resulting creep rate will be much greater than that for a constant stress of 30,000 psi. It can also be stated that the "effective stress" in this case is greater than the mean stress. At 25,000 psi. the stress concentration factor was chosen such that the additional flow occurred only at the maximum stress, so that the effective stress was just equal to the mean stress. At a lower stress such as 20,000 psi. the maximum stress is only 22,000 psi., and from the above assumptions no additional flow will occur during the oscillating load cycle and, therefore, the effective stress will be less than the mean stress. From Fig. 7, the creep rate for a pulsating load test at 20,000 psi. is only slightly greater that that for a constant load test at the "minimum stress" or 18,000 psi.

How this increase or decrease in minimum creep rate affects the rupture time can be studied by comparing the transition point and rupture strains. Since the first and third stages of creep are shorter than the second stage region of constant strain rate (see Fig. 5) the rupture time in the range of stresses used in these tests is nearly proportional to the transition-point strain divided by the minimum creep rate. If the transition-point strains were the same for both the constant load and pulsating load tests, then the rupture time curves will cross in the same manner as the creep rate curves described above. The data in Table I or Fig. 7 show that the transition-point strains are practically the same for both types of tests, that for the pulsating load tests being slightly lower.

Therefore, the rupture data conforms with that found for the minimum creep rate, since the rupture strength for a pulsating load test is poorer at the higher stresses and greater at the lower stresses than that for constant load test.

CONCLUSIONS

The results reported above and the subsequent conclusions must be tempered by the fact that the properties of specimens from the 14S-T aluminum alloy disk may vary for different positions from which they are obtained. However, from the limited data obtained from these tests the following tentative conclusions are made:

1. The minimum creep rate or rupture time in a pulsating load test may be higher or lower than that for a constant load test of the same mean stress. For this 14S-T alloy at 400 F. the minimum creep rate for a pulsating load test of 20 cycles per sec. is higher for a mean stress above about 25,000 psi. and is lower for lower stresses. The rupture time is poorer for a mean stress above about 22,000 psi. and is greater than that for a constant-load test below this stress.

2. The method of combining the oscillating and mean stresses as shown in Fig. 9 is reasonable in so far as the results of

these pulsating load tests are concerned. Further tests with a greater percentage of oscillating load must be made to obtain a more complete check on this method.

3. This 14S-T alloy disk is notch sensitive, and failure at a point of stress concentration is accelerated by the pulsating load. The specimen under pulsating load at 400 F. broke in the threads until the gage diameter was reduced.

4. The specimens of this 14S-T alloy (solution treated from 940 F. and aged at 340 F.) annealed when held at 400 F. without stress. The decay in hardness after 10 hr. was proportional to the log of time.

5. For either type of loading the strain at rupture increased with decreasing stress while that at the transition point was nearly constant in the range of stresses used in the tests. The strain at the transition point for the pulsating-load tests was slightly lower than that for the constant load tests.

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(4) E. A. Davis, "The Effect of Speed of Testing and Rate of Loading on the Yielding of Mild Steel," *Journal of Applied Mechanics*, Am. Soc. Mechanical Engrs., December, 1938, pp. A–137–140.

(5) A. Nadai and M. J. Manjoine, "High Speed Tensile Tests at Elevated Temperature—Parts II and III," *Journal of Applied Mechanics*, Am. Soc. Mechanical Engrs., June, 1940, Fig. 11.

JOINT DISCUSSION OF PAPERS BY B. J. LAZAN AND M. J. MANJOINE

MR. JOHN M. LESSELLS.[1]—The two papers by Messrs. Lazan and Manjoine respectively are important because they indicate the effect of cyclic stress on the rupture strength or creep rate, and possibly these are the reasons why in gas turbine parts the fatigue aspect is just as important as that of creep.

In recent years reference has been made to fatigue failures of such parts even when operating at these very high temperatures. In this connection my attention has recently been drawn to an English publication[2] which gives interesting data on rupture and fatigue tests at various temperatures. If a selection be made from these data so that the testing time is the same for the rupture and fatigue tests, then such can be tabulated as shown below.

EFFECT OF ELEVATED TEMPERATURES ON THE ENDURANCE LIMIT AND RUPTURE STRENGTH OF SUPERALLOY (AUSTENITIC) STEELS.

	Endurance Limits and Rupture Strengths for 300 hr., psi.					
	80 F.	1100 F.	1200 F.	1300 F.	1380 F.	1450 F.
Tensile strength	103 000	....	....	....	....	....
Endurance limit ($S_m = 0$)	52 000	40 000	36 000	29 000	24 000	19 000
Endurance limit ($S_m + S_a$)	....	44 800 + ±19 000	31 400 + ±22 400	27 000 + ±18 700	20 000 + ±19 400	13 400 + ±12 800
Maximum stress of cycle	....	63 800	53 800	45 700	39 400	26 200
Rupture strength	....	54 000	40 000	29 000	22 400	18 000

On this basis a plot can be made using the rupture test data as abscissae to represent the steady stress component and the various fatigue tests to supply the ordinates; then a family of curves can be drawn which are of use to the designer.

The data given in the table will enable a family of five such curves to be drawn.

It is of interest to observe that the effect of cyclic stress is actually to strengthen the material against creep action since the maximum stresses in the case of cyclic stress are in excess of the rupture stress for that particular temperature.

My belief is that the work of Messrs. Manjoine and Lazan should be extended and this may eventually lead to a revision of our conception regarding creep phenomenon.

MR. LEO SCHAPIRO.[3]—I should like to ask Mr. Lazan about the normal curve as we think of it in terms of static loading. I presume that creep in the dynamic test has been measured right up to rupture since curves for $\frac{1}{2}$ per cent and 2 per cent creep are given.

I am rather interested in seeing whether the creep curve, extension *versus* time, in the fatigue test is similar, in showing three stages, to that obtained in the case of static loading. Is the difference in shape dependent on temperature or stress amplitude?

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[1] Associate Professor Mechanical Engineering, Engineering Dept., Massachusetts Institute of Technology, Cambridge, Mass.

[2] Booklet of Mond Nickel Co. on Nimonic Series of Alloys 1949

[3] Chief Metallurgist, Materials Lab., Douglas Aircraft Co., Inc., Santa Monica, Calif.

MR. R. C. A. THURSTON[4] (*presented in written form*).—Mr. Lazan has presented a stimulating paper on the effect of superimposed dynamic loads in stress-rupture testing. He is to be complimented on the wealth of information he has derived from his test data, and the contribution he has made to our limited knowledge of high temperature fatigue. This should prove most encouraging to other workers in this field.

Probably the most interesting feature of the paper is the fact that, for the four materials tested, the addition of alternating stresses at 1500 F. has very little effect on the allowable static stress for a given rupture time or percentage creep. Under certain conditions, low stress and long time tests, the mean stress may even be increased. These results agree substantially with some previous work carried out in England on G18B at temperatures from 700 C. (1290 F.) to 800 C. (1470 F.); in this case the strengthening effect on rupture time was slightly more marked. Other unpublished work on Nimonic 80 at 650 C. (1200 F.) has indicated that similar results will be obtained with superimposed dynamic bending, — conditions approximating those in the turbine bucket. It will be interesting to know whether the author's metallographic examination offers any explanation of this behavior.

There is one other factor involved which requires consideration and that is the speed of the dynamic loading. Is there an effect of speed *per se* at high temperatures, over and above the associated time effect? Little evidence is available on this point as yet, but the results of tests by Bernhardt and Hanemann on lead at room temperature show a definite dependence of creep rate on testing speed. Here, however, the position is complicated by the incidence of recrystallisation phenomena.

With regard to the type of fracture, I would like to ask to what extent transcrystalline fractures were obtained, as opposed to intercrystalline? Was there any relationship between the type of fracture and the static stress level, or the vibration amplitude—mean stress ratio?

At the Bureau of Mines, in Canada, we have been conducting a research along these lines on Nimonic 80 and Inconel X. This work is in its early stages and is being carried out on a similar type of machine, with an alternating stress - mean stress ratio of about 0.85. Tests completed to date at 750 C. (1380 F.) are in agreement with the author's findings, but we have still a long way to go. This latter statement has a general application, since the subject of the present paper is largely an unexplored field. The technical data published so far on high temperature fatigue is scattered over a wide range of machines with a variety of stressing conditions and testing speeds, while data on dynamic creep is difficult to find outside of a few German papers. We can, I am sure, look forward with confidence to further information from the battery of machines at Syracuse.

MR. H. F. MOORE.[5]—Referring to Mr. Manjoine's paper in tests of specimens cut from cable sheathing Mr. Dollins has found that vibratory loads superimposed on dead load generally shortened the life of the specimen, although some exceptions have been found. May it not be possible that the effect of vibratory load may be different in the case of a very soft "creepable" metal like lead from the effect in the case of a metal like an aluminum alloy in which the ratio of elastic strength to ultimate strength is much higher than in the case of lead?

I might add that some of our tests at

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[4] Metallurgical Engineer, Physical Metallurgy Division, Bureau of Mines, Ottawa, Ontario, Canada.

[5] Research Professor of Engineering Materials, Emeritus, University of Illinois, Urbana, Ill.

the University of Illinois have been run for 1000 hr.

MR. M. J. MANJOINE (*author's closure*).—I wish to thank Mr. Lessells for his discussion. It does not call for any comment except that it substantiates the results that both Mr. Lazan and I have found.

For the lead material reported by Mr. Moore, it may be possible to get a better correlation with this aluminum alloy, 14S-T. In this paper it was assumed that a certain stress concentration factor was necessary to explain some of the results. In a recent paper[6] it was reported that by superimposing a slight alternating stress on a steady stress below the yield stress for a period of only 10 to 20 sec. it was possible to extinguish the Kikuchi lines in an electron diffraction reflection pattern. This experiment indicates that the strains resulting from this short loading cycle are so minute that they are not detectable by any other means. By further experiments they concluded that these strains generate at the surface and progress inward. Thus the strain was varying from the surface to the interior. Any recrystallization or other metallurgical change which may affect or be affected by these strains will start at these points of strain. If we can, therefore, discover the effect of these metallurgical factors, there may be some hope in correlating the lead tests with these tests.

MR. B. J. LAZAN (*author's closure*).—The condensation of this paper to a reasonable length required the omission of most of the primary and intermediate curve sheets from which the summary curves of Figs. 16 to 19 were derived. These omitted curve sheets show, in answer to Mr. Schapiro's question, that the general shape of the creep *versus* time curves under dynamic loading is essentially the same as under static loading. Both types of loading at both testing temperatures generally induce the familiar three stages of creep. However, the scope of the tests should be noted in reference to the above statement; tests herein reported cover relatively short times by creep testing standards, include alternating to mean stress ratios under 0.67 only, and the testing temperature range, 1350 F. to 1500 F., was rather narrow. Lower stress, longer duration tests, or higher stress ratios for other testing temperatures may display differently shaped creep curves.

Although the general shape of the static and dynamic creep curves are similar, it should be noted that the third stage creep under dynamic conditions is generally less pronounced. This may be inferred from the stress range *versus* per cent elongation curves shown in Fig. 20. Also, the ratio of creep rate and total creep under static force to those under dynamic conditions depend greatly upon the stress level and the duration of the test. The difference in slope of the 2 per cent and 0.5 per cent creep *versus* time curves for N-155, for example, in Fig. 15, is typical for the materials studied. In order further to clarify this difference in slope, the data plotted in Fig. 16 for N-155 has been rearranged in the accompanying Fig. 1 with some additional long-duration data added for completeness. The general trend in the slope of the original creep *versus* time curves can be inferred from the trend of decreasing negative slope which is displayed in Fig. 1 with increasing duration of test.

The rupture data presented by Mr. Lessells on Nimonic alloy are significant not only because they indicate the relatively small effects of cyclic stress on rupture, but also because they confirm the trend shown in Fig. 21. These

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[6] Heidenreich and Stockley, "Study of Slip in Aluminum Crystals by Electron Microscope and Electron Diffraction Methods," *Physical Society*, London, pp. 57–74 (1948).

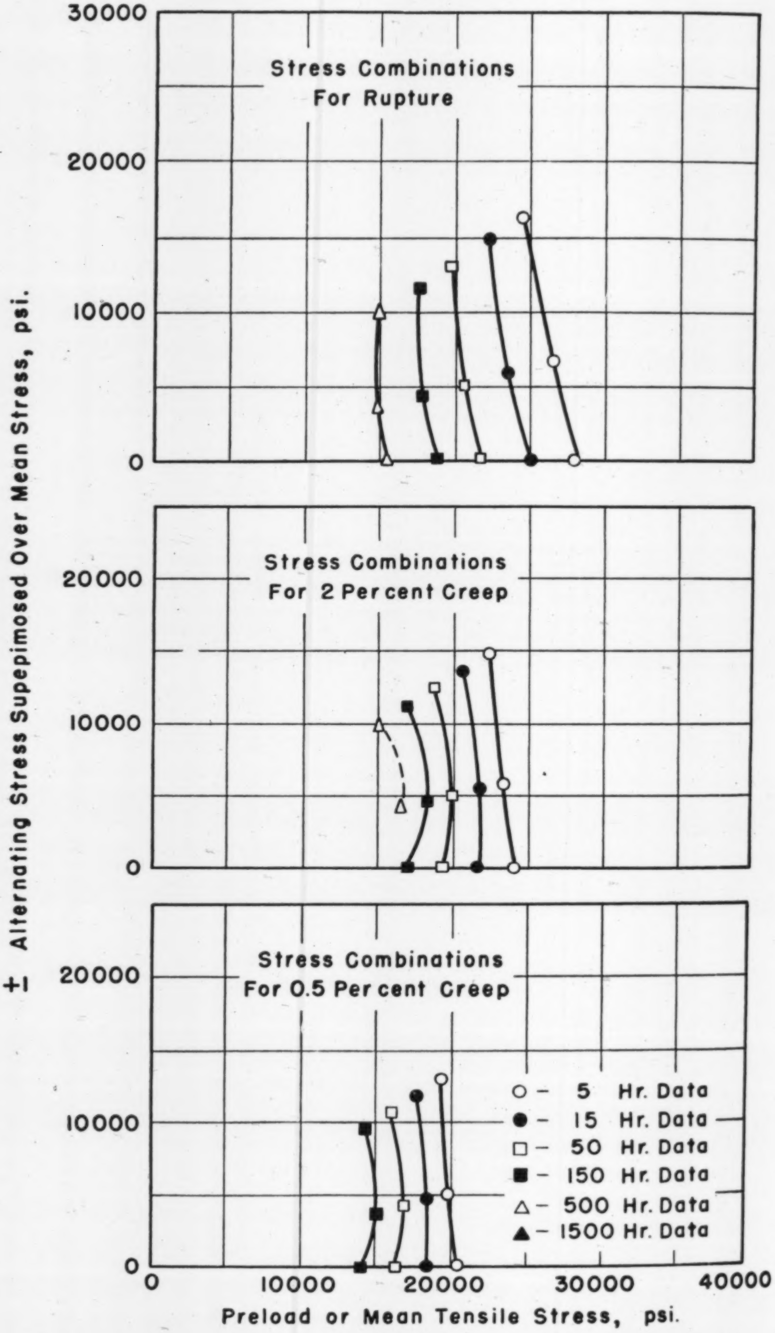

FIG. 1.—Static and Dynamic Stress Combinations Which Cause Rupture, 2 and 0.5 per cent Creep in Hours Indicated For N-155 at 1500 F.

Nimonic alloy data were plotted within the coordinate system used in Figs. 16 to 19 and the mean static to dynamic equivalence ratio E were determined. For a stress ratio A 0.67 the values determined for Nimonic alloy are given below:

Temperature, deg. Fahr.	1100	1200	1300	1380	1450
Equivalence Ratio E	0.7	0.8	0.93	0.97	0.82

Except for the 1450 F. value, the equivalence ratio decreases significantly with decreasing temperatures which is the same trend shown in Fig. 21 for the materials reported in this paper.

Data on the significance on speed of loading as a factor in the dynamic behavior of materials, discussed by Mr. Thurston, may provide a partial explanation of some of the patterns and trends observed. As mentioned in the Appendix, the differences between the theoretically derived dynamic creep curves and the experimentally measured curves are possibly explainable on the basis of either (1) metallurgical changes induced by cyclic stress, or (2) speed of loading effects. The metallurgical factor is now under study and work on the speed of loading effects is now being planned.

In connection with Mr. Thurston's question regarding the correlation of intercrystalline and trans-crystalline facture with type of loading, metallographic and fracture studies have recently been started to answer such questions. These have not yet progressed sufficiently to justify a general statement.

The author is very grateful to the discussors for their aid in clarifying some of the questions associated with the evaluation of temperature resistant materials.

FATIGUE CHARACTERISTICS OF ALUMINUM ALLOY 75S-T6 PLATE IN REVERSED BENDING AS AFFECTED BY TYPE OF MACHINE AND SPECIMEN*

By T. T. Oberg[1] and R. J. Rooney[1]

Synopsis

The data presented by Fuller and Oberg (1)[2] in 1947 were obtained on specimens taken from random locations in an extrusion of heat-treated aluminum alloy (75S-T6). The data in the present paper are based on more numerous tests on specimens from a single plate. Vibratory non-rotating cantilever fatigue tests were made in a Krouse plate fatigue machine (fixed deflection), using test specimens of round, square, and rectangular critical sections. Rotating-beam specimens (round) were tested in an R. R. Moore type rotating-beam (constant load) fatigue-testing machine. All specimens were machined to a critical thickness or diameter of $\frac{1}{4}$ in. from the $\frac{3}{8}$-in. plate. Fatigue curves were obtained for the various shapes. The round specimens showed the highest fatigue strengths, the non-rotating being higher than the rotating. The square specimen developed higher fatigue strengths than those of rectangular cross-section.

The published data for direct comparison of the fatigue characteristics of various shapes of specimens tested in the R. R. Moore rotating simple beam and the Krouse plate fatigue testing machines are limited. For this reason tests were made for the purpose of obtaining additional comparative data. Specimens of various geometric shapes were prepared from a single plate of 75S-T6 aluminum alloy. It appears that the shape and size of specimen are important factors in determining the fatigue strength of the material, especially as noted for the non-rotating flat and round specimens. The latter had the least surface area at the region of maximum stress and developed the highest fatigue value. However an increase in this critical area as in case of square and rectangular specimens was associated with a decrease in the fatigue strength. The results of this investigation are in general agreement with those in papers by Fuller and Dolan (**1**, **2**, **3**).

Material

An aluminum alloy 75S-T6 (75S-T old designation) plate, $\frac{3}{8}$ in. thick, 2 ft. wide and 10 ft. long was purchased from the Aluminum Company of America. The chemical analysis conformed to the following Army-Navy Aeronautical Specification AN-A-9a.

	Chemical Composition, per cent
Zinc	5.1 to 6.1
Copper	1.2 to 2.0
Magnesium	2.1 to 2.9
Manganese	0.10 to 0.30
Chromium	0.15 to 0.40
Titanium	0.20 max.
Silicon	0.5 max.
Iron	0.7 max.
Aluminum	Remainder

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] Chief, and Materials Testing Engineer, respectively, Fatigue and Vibration Unit, Engineering Division, Materials Laboratory, Air Materiel Command, Wright-Patterson Air Force Base, Dayton, Ohio.

[2] The boldface numbers in parentheses refer to the references appended to this paper, see p. 812.

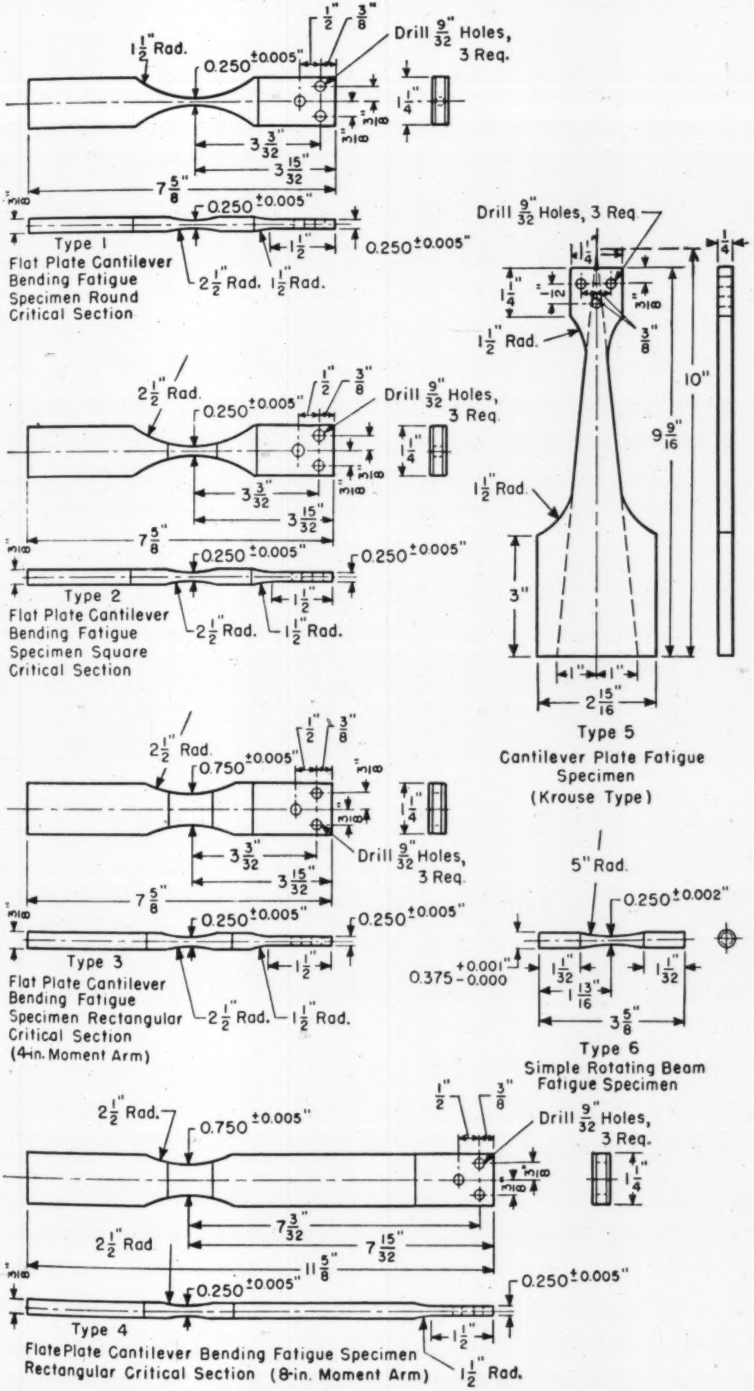
1½" Rad.
0.250 ±0.005"
½"
⅜"
Drill 9/32" Holes, 3 Req.
1¼"
⅜"
⅜"
3 3/32"
3 15/32"
7⅝"
⅜"
0.250 ±0.005"
1½"
0.250 ±0.005"
Type 1
Flat Plate Cantilever Bending Fatigue Specimen Round Critical Section
2½" Rad.
1½" Rad.
2½" Rad.
0.250 ±0.005"
½"
⅜"
Drill 9/32" Holes, 3 Req.
1¼"
⅜"
⅜"
3 3/32"
3 15/32"
7⅝"
⅜"
0.250 ±0.005"
0.250 ±0.005"
1½"
Type 2
Flat Plate Cantilever Bending Fatigue Specimen Square Critical Section
2½" Rad.
1½" Rad.
2½" Rad.
0.750 ±0.005"
½"
⅜"
⅜"
⅜"
1¼"
Drill 9/32" Holes, 3 Req.
3 3/32"
3 15/32"
7⅝"
⅜"
0.250 ±0.005"
0.250 ±0.005"
1½"
Type 3
Flat Plate Cantilever Bending Fatigue Specimen Rectangular Critical Section (4-in. Moment Arm)
2½" Rad.
1½" Rad.
2½" Rad.
0.750 ±0.005"
½"
⅜"
Drill 9/32" Holes, 3 Req.
⅜"
⅜"
1¼"
7 3/32"
7 15/32"
2½" Rad.
11⅝"
⅜"
0.250 ±0.005"
0.250 ±0.005"
Type 4
1½"
FlatePlate Cantilever Bending Fatigue Specimen Rectangular Critical Section (8-in. Moment Arm)
1½" Rad.
Drill 9/32" Holes, 3 Req.
1¼"
¼"
1¼"
½"
⅜"
⅜"
1½" Rad.
10"
9 9/16"
1½" Rad.
3"
1"
1"
2 15/16"
Type 5
Cantilever Plate Fatigue Specimen (Krouse Type)
5" Rad.
0.250 ±0.002"
0.375 +0.001" −0.000
1 1/32"
1 1/32"
1 13/16"
3⅝"
Type 6
Simple Rotating Beam Fatigue Specimen

FIG. 1.—Types and Dimensions of Specimens.

TABLE I.—TENSILE PROPERTIES FOR 75S-T6 ALUMINUM ALLOY.

Specimen axis Relative to Rolling	Tensile Strength, psi.	Yield Strength at 0.2 per cent Offset, psi.	Elongation, per cent[a]
$\frac{3}{8}$ BY $\frac{1}{2}$-IN. RECTANGULAR SPECIMENS			
L-1 Longitudinal	84 200	76 900	12.5
L-2 Longitudinal	84 200	77 000	11.0
Avg.	84 200	76 950	11.8
T-1 Transverse	81 900	71 600	11.0
T-2 Transverse	82 500	73 000	12.5
Avg.	82 200	72 300	11.8
$\frac{1}{4}$-IN. DIAMETER ROUND SPECIMENS			
L-1 Longitudinal	84 200	77 200	11.0
L-2 Longitudinal	84 600	77 500	11.0
L-3 Longitudinal	84 500	77 600	11.0
Avg.	84 400	77 400	11.0
T-1 Transverse	82 600	72 700	11.0
T-2 Transverse	82 400	73 200	10.5
T-3 Transverse	82 100	72 700	11.5
Avg.	82 400	72 900	11.0

[a] In 2-in. for rectangular specimens; in 1-in. (equal to 4*D*) for round.

TABLE II.—FATIGUE PROPERTIES IN REVERSED BENDING FOR VARIOUS TYPES OF TEST SPECIMENS OF 75S-T6 ALUMINUM ALLOY.

Type of Specimen	Longitudinal[a]				Transverse[a]			
	10^5 Cycles	10^6 Cycles	10^7 Cycles	10^8 Cycles	10^5 Cycles	10^6 Cycles	10^7 Cycles	10^8 Cycles
Type 1—cantilever round section	47 500	40 000	33 000	29 000	....	37 000	29 000	24 000
Type 6—simple rotating beam	47 500	38 500	31 500	25 000	40 000	30 500	26 000	22 000
Type 2—cantilever square section	....	33 500	25 500	21 000	....	29 500	23 500	20 000
Type 5—cantilever constant strength (Krouse)	42 500	29 500	21 500	18 500	42 500	28 500	23 000	20 000
Type 4—cantilever rectangular critical section 8-in. moment arm	45 000	29 000	20 000	18 500	....	....	....	....
Type 3—cantilever rectangular critical section	45 000	26 000	19 000	17 500	....	....	....	....

[a] Axis of specimen relative to direction of rolling.

The heat treatment consisted of a solution treatment in the temperature range of 916 to 930 F. followed by artificial aging for 6 hr. at a furnace temperature of 210 F., cooling to room temperature and reheating for 10 hr. at a furnace temperature of 315 F. and cooling in air to room temperature.

PROCEDURE

Specimens of the following types were machined from the plate:

Type 1.—Plate cantilever, round critical section.

Type 2.—Plate cantilever, square critical section.

Type 3.—Plate cantilever, rectangular critical section, 4-in. moment arm.

Type 4.—Plate cantilever, rectangular critical section, 8-in. moment arm.

Type 5.—Plate cantilever, rectangular critical section, Krouse type.

Type 6.—Rotating beam, round critical section.

The specimens were both parallel and transverse to the direction of rolling except those of rectangular critical section, types 3 and 4, which were parallel only. The critical sections of the round and flat fatigue specimens were machined so that the extreme outer fibers subjected to maximum stress were at the same distance under the surface of the $\frac{3}{8}$-in. plate. The types and dimensions are shown in Fig. 1. The round specimens, types 1 and 6 were polished in a superfinishing machine to approximately 10 microinches. The square and rectangular specimens, types 2, 3, 4, and 5, were finished by hand with No. 00 grit polishing paper and the sharp corners were reduced slightly with No. 1 and No. 00 polishing paper to approximately 20 microinches.

Cantilever specimens, types 1 to 5 inclusive, were tested in reversed bending in a Krouse cantilever-plate fatigue machine at an operating speed of 1750 rpm. The rotating beam specimens, type 6, were tested in reversed bending in R. R. Moore type rotating-beam

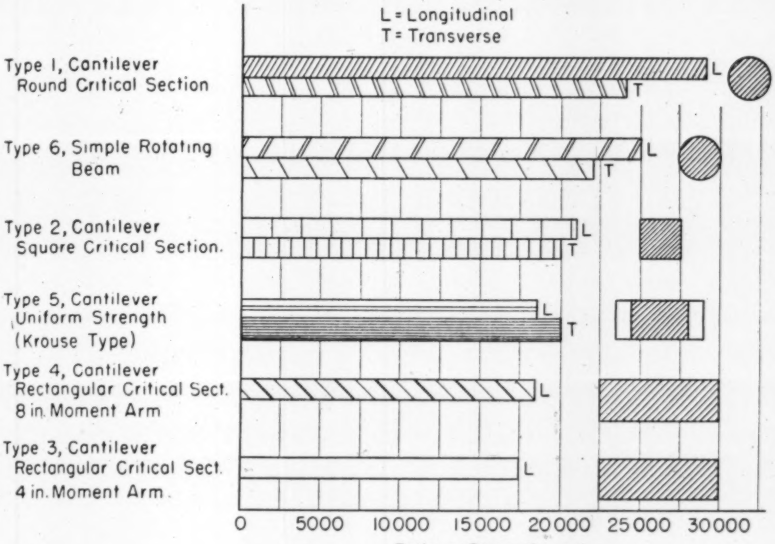

FIG. 2.—Effect of Specimen Shape on Reversed Bending Fatigue Strength of 75S-T6 Aluminum Alloy at 10^8 Cycles.

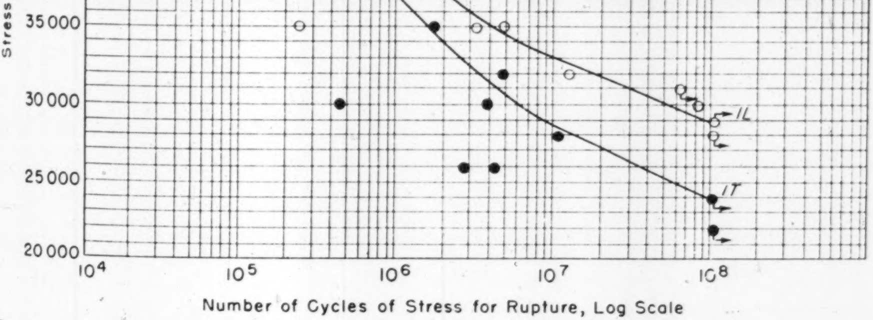

FIG. 3.—Stress-Cycle Diagrams for Reversed Bending Cantilever Non-Rotating Beam Specimen—Type 1 Round Section—75S-T6 Aluminum Alloy.

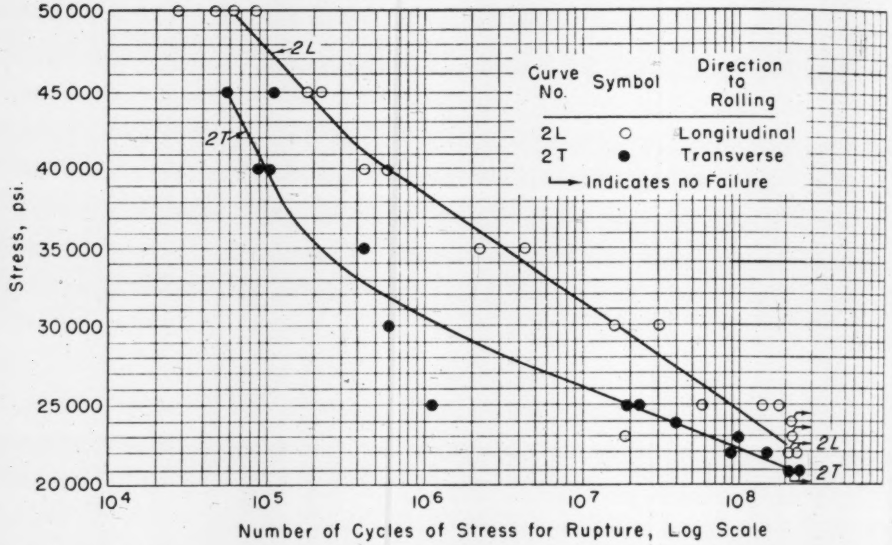

FIG. 4.—Stress Cycle Diagrams for Reversed Bending Rotating Beam Specimen Type 6 Round Section 75S-T6 Aluminum Alloy.

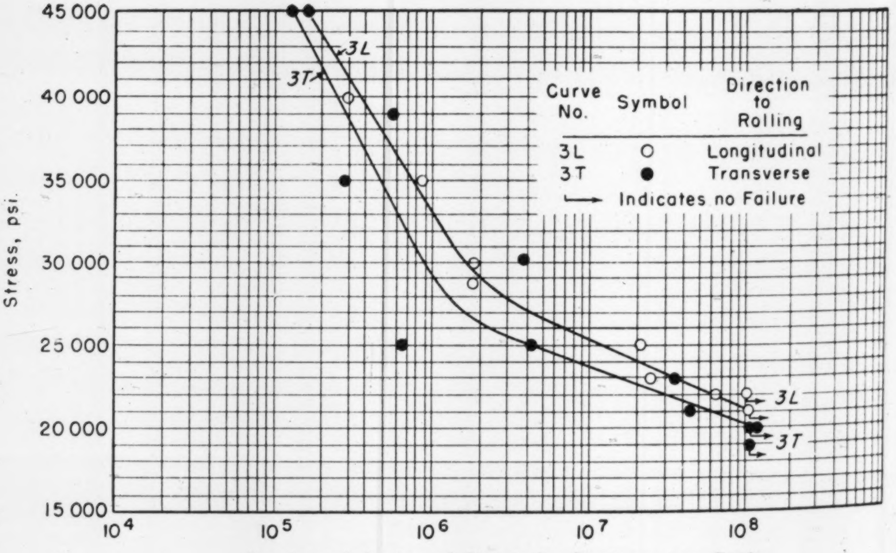

FIG. 5.—Stress-Cycle Diagrams for Reversed Bending Cantilever Specimen Type 2 Square Section 75S-T6 Aluminum Alloy.

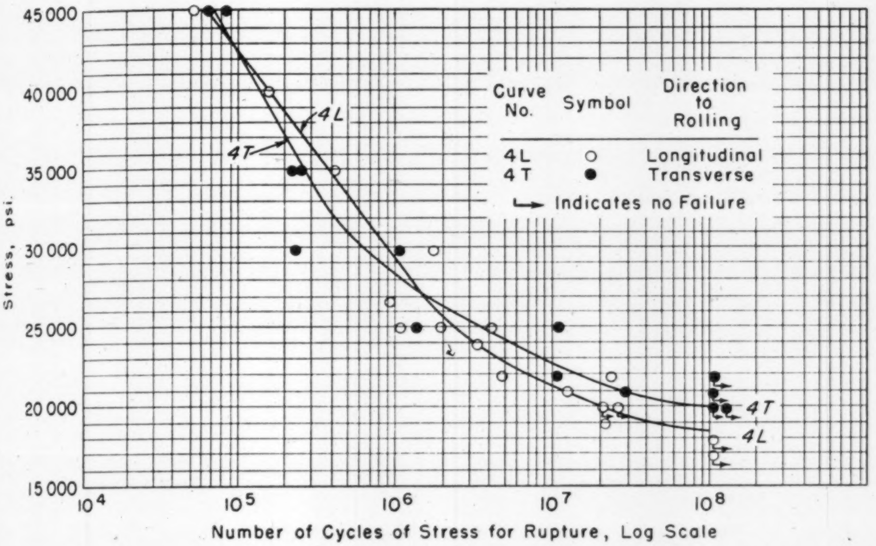

FIG. 6.—Stress Cycle Diagrams for Reversed Bending Cantilever Specimen Rectangular Section Constant Strength (Krouse Type 5) 75S-T6 Aluminum Alloy.

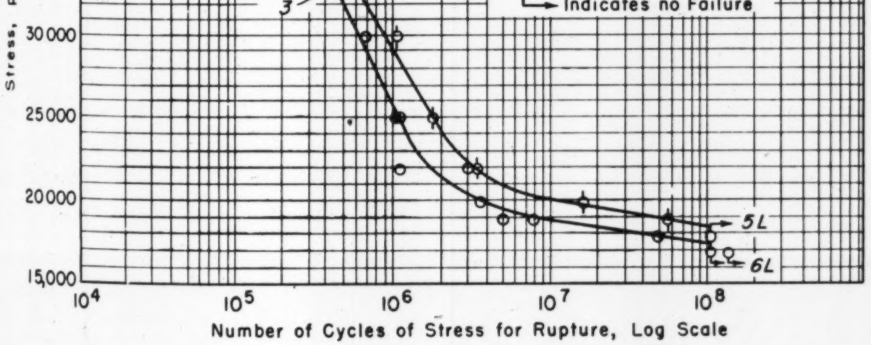

FIG. 7.—Stress Cycle Diagrams Reversed Bending Cantilever (Specimen Type 3 and 4) Rectangular Section 75S-T6 Aluminum Alloy.

fatigue machines at operating speeds of 3450 and 10,000 rpm. Faired fatigue curves were drawn "by eye" for each specimen type in Figs. 3 to 7 inclusive. Standard tension specimens were taken from various locations in order to check uniformity of the plate. Round specimens, with a $\frac{1}{4}$-in. diameter and a gage length of 1 in., and $\frac{3}{8}$ by $\frac{1}{2}$-in. rectangular specimens with two sides representative of the original surface of the plate, were used.

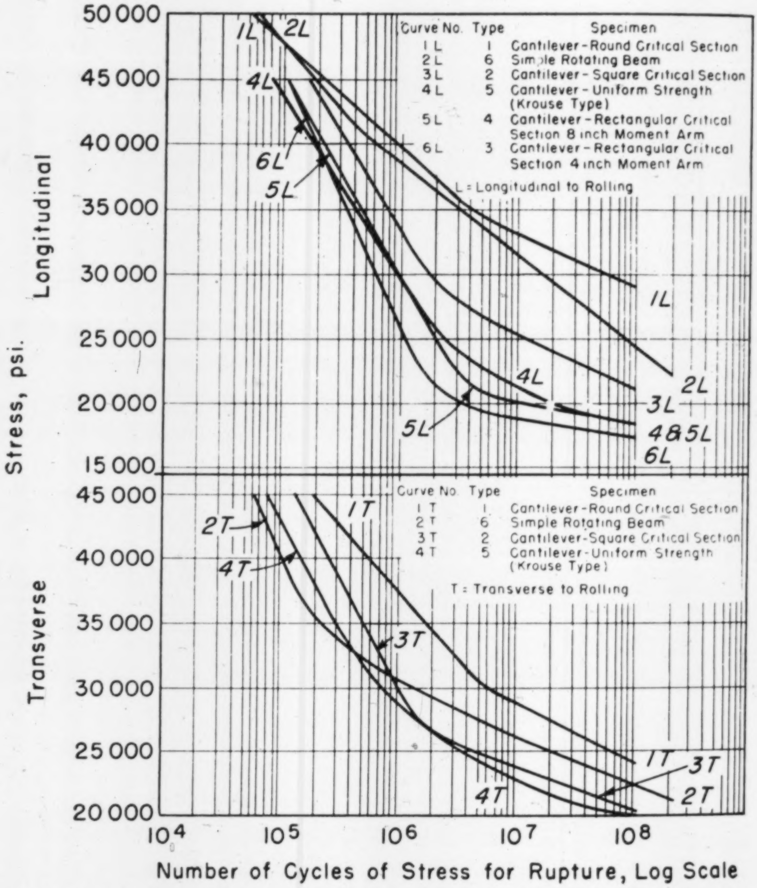

FIG. 8.—Stress Cycle Diagrams for Reversed Bending 75S-T6 Aluminum Alloy.

RESULTS AND DISCUSSION

In Table I it will be noted that the tensile properties are very uniform relative to different locations in the plate and to shape and surface finish of the specimens.

Table II shows the fatigue strength at various numbers of cycles. The data for the transverse direction for a specific type of specimen were lower in general than those for the longitudinal direction except for the type 5 plate cantilever of constant strength. The rectangular specimens were lowest in fatigue strength, the short type being lowest. Fig. 2 is a graphical representation of the fatigue strengths at 100 million cycles.

In Fig. 8 are given the *S-N* curves for the types of specimens tested. For the parallel-to-rolling direction, the data indicate that all specimens would be approximately equal in endurance at high stresses. However at low stresses a wide variation in fatigue strengths is noted; the cantilever with round critical section at 100 million cycles being approximately 65 per cent higher than the short cantilever with rectangular critical section. For transverse-to-rolling direction, the variation in fatigue characteristics appears to be less than that shown by the longitudinal specmens, while the scatter of the individual test data is much greater. The individual test data are shown in the individual *S-N* curves in Figs. 3 to 7 inclusive.

Since the maximum stress, as calculated from the flexure formula $\frac{M_c}{I}$, is imposed on the outer fibers of the critical section of each type of beam, the volume of material under maximum stress will differ for each type. The non-rotating cantilever with round critical section will have only a small amount on top and bottom subjected to the maximum stress and the rotating beam will have a volume proportional to the smallest circumference. The square and rectangular cantilevers will have volumes proportional to the widths on top and bottom surfaces at the critical sections, subjected to maximum stress and the constant strength specimens will have comparatively large volumes.

From a statistical basis, the Krouse specimens indicate that the area of surface fiber resistance in the region of peak stress appears to be related to the fatigue since the non-rotational round specimen had lesser area and higher fatigue characteristics compared to long rectangular specimen of greater area and lower fatigue strength. Also for the rectangular specimens there was an indication that the one of smaller area had a higher fatigue strength, except that the tapered specimen of uniform theoretical stress section did not fall in line. The round rotating-beam specimen (constant load) had greater area than the square rectangular type constant deflection with also a higher fatigue strength. There are several factors such as constant load *versus* constant deflection for the two types of round specimens, and the corner effects for the rectangular specimens compared with the round type in the constant-deflection machines that must be considered. After critical study, it is believed that a better study of the specimens in the Krouse machine would have been obtained if a round specimen rotating under constant deflection also were tested. Because of the uniformity of the material, it is believed that these fatigue data indicate that the fatigue characteristics of a material are a function of specimen shape.

At 100 million cycles the rectangular specimen with the long moment arm had a fatigue strength of approximately 18,500 psi. as compared to 17,500 psi. for the rectangular type with short moment arm. In testing the rectangular beams with short moment arm comparatively high external forces were required to produce the desired stresses in the test section. All but two of the short rectangular specimens failed outside the minimum or critical section, some at sections where the calculated stress was approximately 85 per cent of that for the minimum section. All stresses reported herein are those calculated for for the minimum section of the specimen. The purpose of the investigation was to determine the reactions of various types of fatigue specimens to the same theoretical stresses at the critical sections. The fatigue fractures in the square and rectangular specimens started at the corners.

The long rectangular specimens all failed at or very close to the minimum section and gave consistently higher fatigue characteristics.

It is believed that the variations in fatigue strengths for the various types of specimens used can be attributed solely to the shape of critical section, although the methods of finishing may have had a very slight effect. The round specimens were turned in a lathe and superpolished in a superfinishing machine to an average finish of 10 microinches. The square and rectangular specimens were milled to the proper critical dimension with a 5-in. cutter and hand polished to an average finish of 20 microinches. The uniform strength (Krouse type) specimen was machined in a shaper to the proper thickness and hand polished to approximately the same microfinish as those for rectangulars. Oberg and Johnson have (7) indicated that the operating frequencies at which the rotating-beam tests were made should have no appreciable effect upon the fatigue properties of the material.

NACA Technical Note 852 reports results of vibratory reversed-bending fatigue tests using specimens similar to those used in tests reported herein. The rectangular specimens exhibited a fatigue strength 31 per cent less than that shown by the round specimens; the square specimens had a fatigue strength 23 per cent less than the round specimen. In the test reported herein the fatigue strengths of the long and short rectangular specimens were 36 and 40 per cent less than that of the round specimens respectively. The square specimens had a fatigue strength 27 per cent less than round. The above fatigue strengths are based on 10^8 cycles. Based on difference in tensile strengths of the two aluminum alloys, a comparison of test results of fatigue ratios (fatigue strength to tensile strength) gives the following relation:

	Round	Square	Rectangular
N.A.C.A.—852............	0.332	0.255	0.228
Wright-Field..............	0.354	0.255	0.225 long 0.212 short

REFERENCES

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(2) T. J. Dolan, "Effects of Range of Stress and of Special Notches on Fatigue Properties of Aluminum Alloys Suitable for Airplane Propellers," *Technical Note No. 852*, National Advisory Committee of Aeronautics, June, 1942.

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(4) "The Effect of Type of Testing Machine on Fatigue Test Results," Report of the Research Committee on Fatigue of Metals, *Proceedings*, Am. Soc. Testing Mats., Vol. 41, p. 133 (1941).

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DISCUSSION

Mr. W. G. Schreitz.[1]—I should like to ask whether the corners of the specimens were square or rounded.

Mr. T. J. Dolan.[2]—I understand that the corners on the rectangular specimens were rounded very slightly by polishing by hand with a No. 1 grit emory paper followed by No. 00 polishing paper—just enough to remove the sharp fin and sharp corner on the edge of the specimen in an attempt to get the same type of polish as on the surfaces of the specimen.

Mr. Schreitz.—We have done the same thing in steel specimens, and we had noticed quite a bit of difference due to the radius.

Mr. H. F. Moore.[3]—Both in fatigue tests and in creep tests of rectangular specimens we have found at the University of Illinois that the removal of any "fins" left at the corners after machining increases the strength of the specimen materially. Such "fins" seem to be quite effective as stress raisers.

Mr. Dolan.—In comparison with the results presented on 75S-T6 alloy it may be of interest to note that in tests at the University of Illinois[4] somewhat similar studies were made of two steels and the data obtained were comparable with that presented by the authors. In these tests an attempt was made to evolve several shapes of specimen that did not have the same amount of material at peak stress, and flexural fatigue studies were finally made of beams having the following shapes of cross-section: (*a*) round; (*b*) square, with neutral axis parallel to one edge; (*c*) square with neutral axis as a diagonal of the square; and (*d*) the same specimen as type (*c*) but with a small portion of the extreme fiber removed at top and bottom of the beam. The results indicated that the round cross-section was superior in fatigue strength to any of the other shapes tested even though other beams such as type (*c*) had a smaller amount of material on the extreme fiber and subjected to the peak stress. Thus the volume of material in the region of peak stress did not appear to be the only factor controlling the altered fatigue properties of these cross-sections; some of the inelastic readjustments that occur throughout the duration of a fatigue test are perhaps fully as important as the amount of material at peak stress. One must recognize that under conditions imposed by repeated loading, metals are not perfectly elastic or they would not fail in fatigue. Nominal stress calculations employing the flexure formula are therefore in error, and a full explanation of these shape effects must in some manner be concerned with the susceptibility to localized inelastic action as governed by the shape of cross-section.

Mr. T. T. Oberg (*author's closure*).—The method of finishing the corners on the gage section of the square and rec-

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[2] Research Professor of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

[3] Research Professor of Engineering Materials, Emeritus, University of Illinois, Urbana, Ill.

[4] T. J. Dolan, J. H. McClow and W. J. Craig, "The Influence of Shape of Cross-Section on the Flexural Fatigue Strength of Steel," Tenth Progress Report on Contract N6-ori-71, T.O. IV, Engineering Experiment Station, University of Illinois, December, 1948. (To be presented at Annual Meeting of American Society of Mechanical Engineers, December, 1949.)

TABLE III.—A COMPARISON OF THE FATIGUE LIMIT FOR R. R. MOORE ROTATING-BEAM SPECIMEN WITH RECTNAGULAR, SQUARE AND ROUND CANTILEVER NON-ROTATING-BEAM SPECIMENS.

Type Specimen	Material	Condition	Ultimate Tensile Strength, psi.	Elongation, per cent	Fatigue Limit, psi.
Rectangular Cantilever	18-8	Annealed	86 000	49.0	35 000
Round Rotating Beam R. R. Moore		Annealed	86 900	60.0	35 000
Round Rotating Beam R. R. Moore	S.A.E. 4130	Heat Treated^a	129 000	17.0	73 000
Rectangular Cantilever		Heat Treated^a	129 000	17.0	62 000
Rectangular Cantilever		Heat Treated^b	150 000	14.5	72 000
Round Rotating Beam R. R. Moore		Heat Treated^b	150 000	14.5	85 000
Round Rotating Beam R. R. Moore		Heat Treated^c	206 000	10.0	115 000
Rectangular Cantilever		Heat Treated^c	206 000	10.0	74 000
Fatigue Strength at 100 000 000 Cycles					
Rectangular Cantilever	Al-Alloy 75S-T6	Heat Treated	84 200	12.5	18 500
Square Cantilever		Heat Treated	84 200	12.5	21 000
Round Cantilever		Heat Treated	84 200	12.5	29 000
Round Rotating Beam R. R. Moore		Heat Treated	84 200	12.5	25 000

[a] Retreated or drawn at 1100 F. for 1 hr., quenched in oil.
[b] Retreated or drawn at 950 F. for 1 hr., quenched in oil.
[c] Retreated or drawn at 650 F. for 1 hr., quenched in oil.

tangular cantilever specimens was as follows. Slight rounding with No. 1 and No. 0 emergy paper. No attempt was made to measure the radius of curvature on the rounded corners. Since the operation was done by hand, there may have been some slight variation.

It appears that the most important factor which affects the fatigue strength of material is the specimen shape. In comparison to the round specimen which has a continuous smooth surface, the fibers on the corners of a rectangular specimen are not supported to the same degree by the adjacent fibers. This would cause a stress gradient near the corners with the results of lower fatigue strength for material of high notch sensitivity.

In Table III is shown a comparison of the fatigue limits for R. R. Moore rotating-beam specimens with those for square, rectangular and round nonrotating cantilever specimens from low and high notch sensitive materials. The values were obtained at Wright-Patterson Air Force Base. Annealed 18 per cent chromium, 8 per cent nickel steel, which has very low notch sensitivity, developed the same fatigue limit for R. R. Moore rotating-beam specimens as that for rectangular cantilever sheet specimens. S.A.E. 4130 steel heat treated to a ultimate tensile strength of 206,000 psi. developed a fatigue limit of 115,000 psi. for R. R. Moore rotating-beam specimen and 74,000 psi. for rectangular cantilever beam specimen or a reduction of approximately 36 per cent.

CREEP AND STRESS-RUPTURE INVESTIGATIONS ON SOME ALUMINUM ALLOY SHEET METALS*

By J. E. Dorn[1] and T. E. Tietz[1]

Synopsis

Increased interest in the elevated temperature properties of aluminum alloys prompted investigations on the creep and stress-rupture characteristics of 3S-H12, 3S-H18, 52S-H32, 52S-H38, 61S-T6, and 24S-T3 (A.S.T.M. Designation M1-H12, M1-H18, GR1-H32, GR1-H38, GS21-T6 and CG21-T3 respectively). From 90 F. to 400 F., the above sequence of alloys was found to be the order of increasing resistance to creep and stress rupture. Cold rolling appears to have a beneficial effect on the creep resistance and the time to rupture.

The data for 3S-H12 and also 3S-H18 were analyzed in terms of Hollomon's theory of creep, but the theory did not correlate well with the experimental facts.

Over the past few years, many engineers have expressed increased interest in using aluminum alloys at elevated temperatures. Stress-rupture and creep data are currently available (1)[2] for some of the precipitation-hardened alloys. But the scope of the previous investigation did not include all of the alloys of current interest. The following program of studies was therefore initiated in order to provide some of the missing data and also to uncover new factors of importance in the creep behavior of aluminum alloys.

Materials

The alloys selected for this investigation, recorded in Table I, may be classified into two major groups: alloys which are not hardenable by precipitation were placed in Class I, and those which are precipitation hardenable were placed in Class II. The actual composition of each alloy, as determined by spectrochemical analysis, is also recorded in Table I.

The materials used in this investigation were obtained from standard commercial stock. The processing of the materials studied was therefore in accordance with common production techniques. It was considered desirable, however, to test material truly representative of the several alloys under study. An attempt was therefore made to select samples of sheet which exhibited almost typical mechanical properties. How closely this was achieved is illustrated in Table II, in which are recorded the typical and actual tensile properties of the materials which were studied.

Experimental Technique

The designs of the creep equipment,

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] Professor of Physical Metallurgy and Research Engineer, respectively, University of California, Berkeley, Calif.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 831.

TABLE I.—CHEMICAL COMPOSITION OF ALLOYS INVESTIGATED.

Class	Alloy and Condition	Typical Composition, per cent alloying elements					Actual Composition,[a] per cent							
		Cu	Si	Mn	Mg	Cr	Cu	Si	Mn	Mg	Cr	Fe	Ti	Zn
I	3S-H12	...	...	1.2	...	...	0.14	0.21	1.05	....	....	0.48	....	0.01
	3S-H18						0.14	0.19	1.04	....	....	0.39	....	0.04
	52S-H32	...	...	...	2.5	0.25	0.05	0.15	0.04	2.59	0.21	0.14	0.01	0.01
	52S-H38						0.04	0.10	0.01	2.45	0.25	0.18	0.01	0.01
II	61S-T6 (bare)	0.25	0.6	...	1.0	0.25	0.21	0.57	0.05	1.01	0.24	0.29	0.03	0.03
	24S-T3 (bare)	4.5	...	0.6	1.5	...	4.87	0.13	0.67	1.43	0.03	0.27	0.02	0.05

[a] Spectrochemical analyses. Data furnished by the Aluminum Company of America.

TABLE II.—MECHANICAL PROPERTIES.

Alloy Designation[b]	Typical[c]			Actual[a]		
	Yield Strength, psi.	Tensile Strength, psi.	Elongation, per cent	Yield Strength, psi.	Tensile Strength, psi.	Elongation, per cent
3S-H12	17 000	19 000	10	19 250	19 950	15.5
3S-H18	26 000	29 000	4	26 450	27 800	5.8
52S-H32	27 000	34 000	12	29 150	35 450	8.5
52S-H38	36 000	41 000	7	35 750	40 600	9.0
61S-T6	40 000	45 000	12	39 900	46 900	15.2
24S-T3	50 000	70 000	19	52 700	72 050	19.5

[a] Data furnished by the Aluminum Company of America.

[b] "Alcoa Temper Designations for Cast and Wrought Products," Aluminum Company of America, Pittsburgh, Pa. The Eddy Press Corp., January 1, 1948.

[c] "Alcoa Aluminum and Its Alloys," Aluminum Company of America, Pittsburgh, Pa. The Eddy Press Corp. (1947).

furnaces, specimens, and extensometers have already been reported (1) and therefore need not be repeated here. The specimens were carefully machined from 0.064 in. thick sheet, the axis of the specimen being selected in the rolling direction. The reduced section of the specimens was 7.5 in. long and 0.500 in. wide; and the gage length used for a determination of the creep strains and the secondary creep rate included the central 6 inches of the reduced section.

Accuracy of Measurements:

Loading of the specimen was obtained through 10:1 levers, to which metal containers holding lead shot were attached. The loads on the specimens were controlled to ±1 lb.

The extensometer dials were graduated in divisions equivalent to 0.005 in. change in gage length. Readings were made to one tenth of a division corresponding to a strain of 0.00008 in. per in.

Temperatures for the 400 F. and 300 F. furnace were maintained constant by boiling glycol-water solutions. Boiling water was used to obtain the 212 F. temperature, and a thermostatic control with water to maintain the 90 F. temperature.

TESTING PROCEDURE

The specimens were inserted into the furnace one hour prior to application of load in order to permit the specimens to obtain the testing temperature. The load was then gradually applied. The extensometer was read and the specimen temperature was determined at periodic intervals during the test. In addition, the time to fracture after application of the load, the type of fracture, and the fracture strain were recorded; also the time for initiation of the secondary and tertiary stages of creep were determined.

EXPERIMENTAL RESULTS

Strain-Time Curves:

The strain as a function of time at the various conditions of stress which were investigated is shown in Figs. 1 to 6. In order to record all of the data with equal accuracy on identical scales, the logarithm of the total strain was plotted

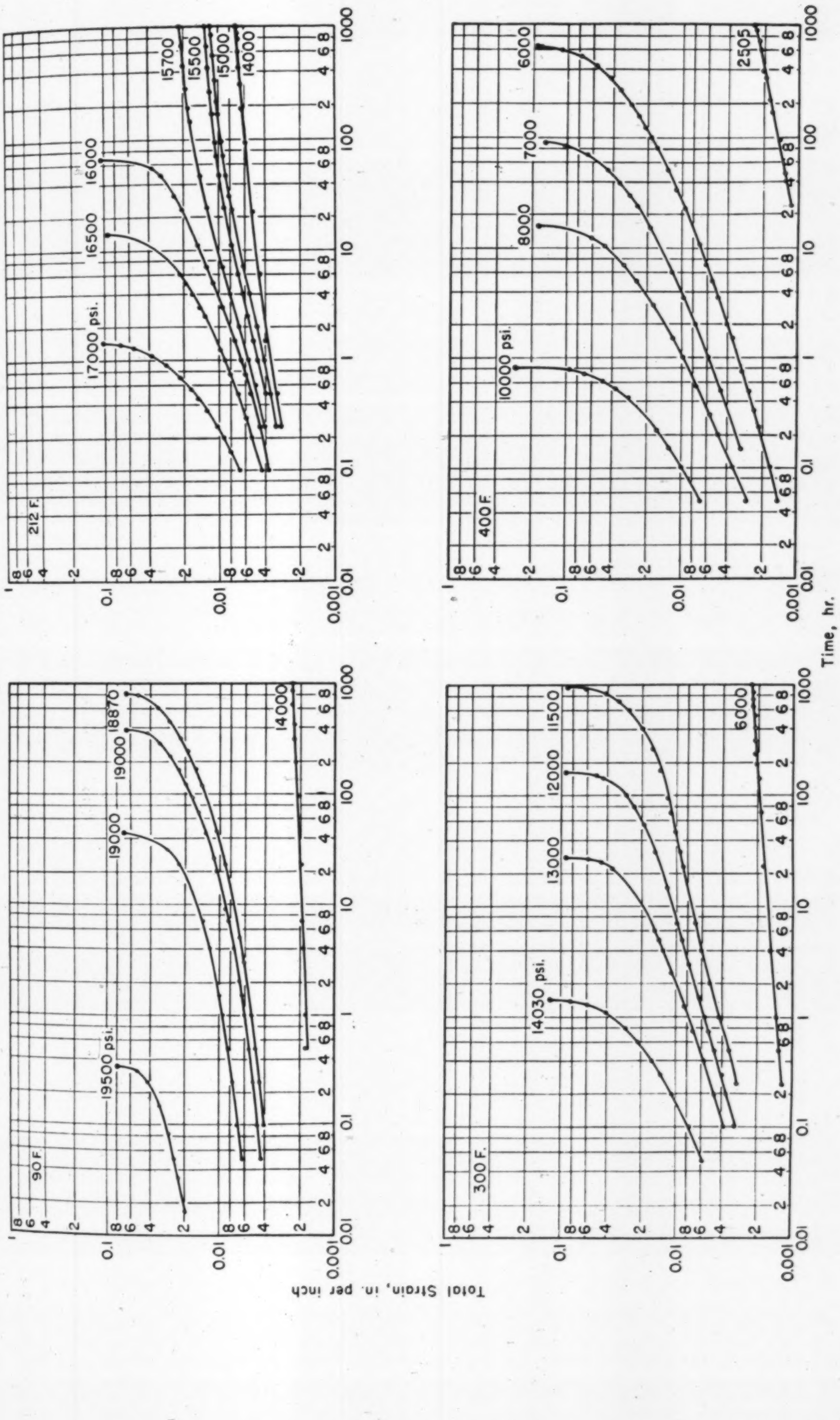


FIG. 1.—Total Creep Strain as a Function of Time for 3S-H12.

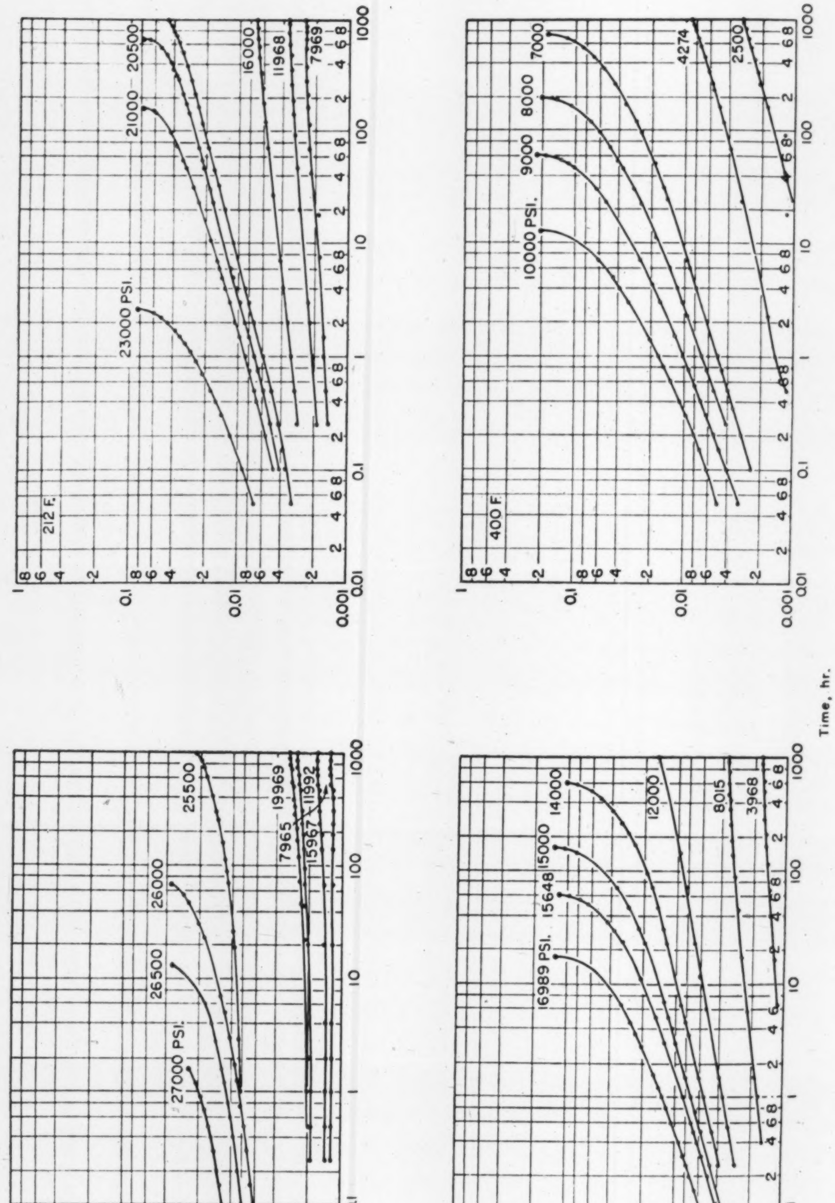


FIG. 2.—Total Creep Strain as a Function of Time for 3S-H18.

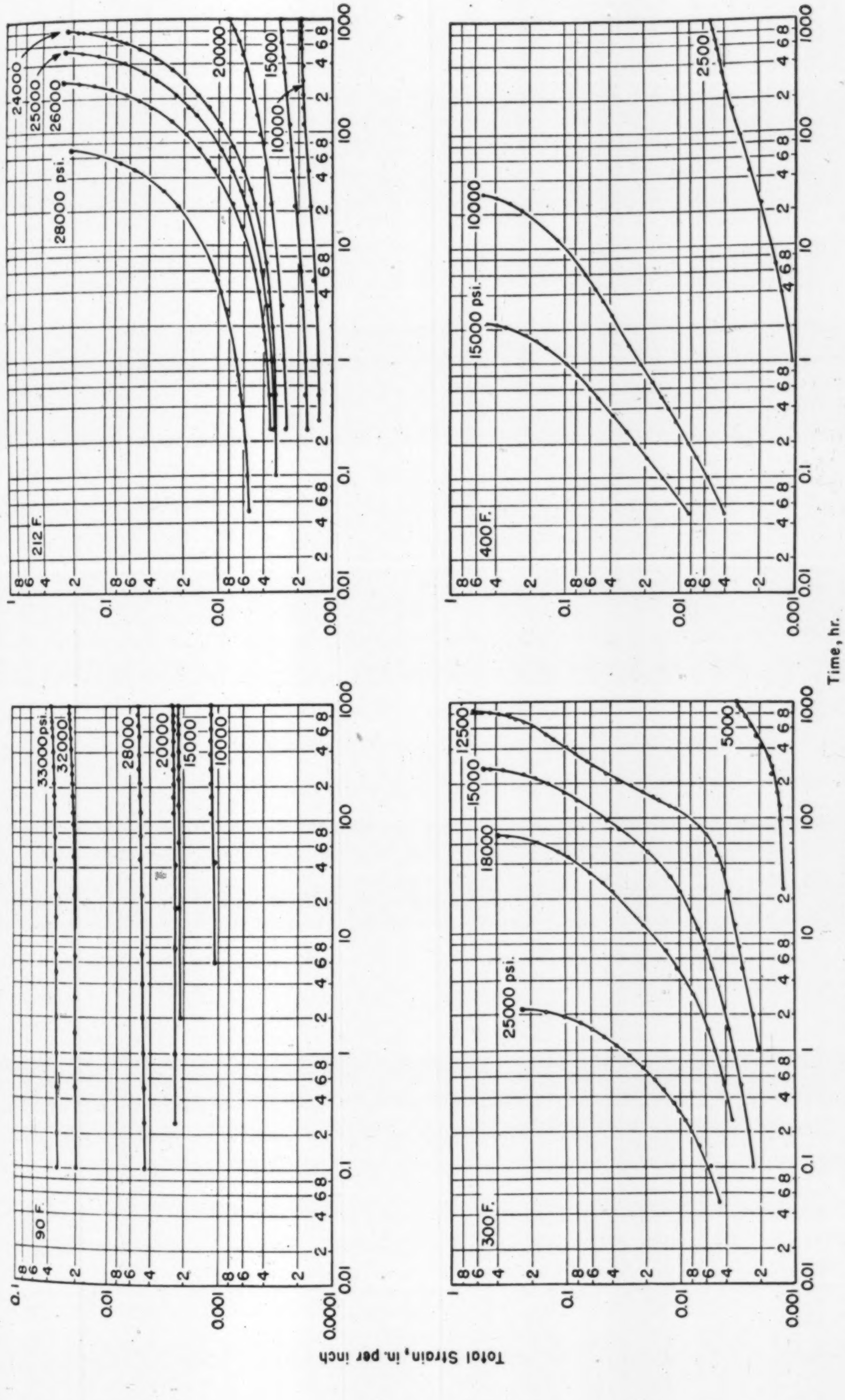


FIG. 3.—Total Creep Strain as a Function of Time for 52S-H32.

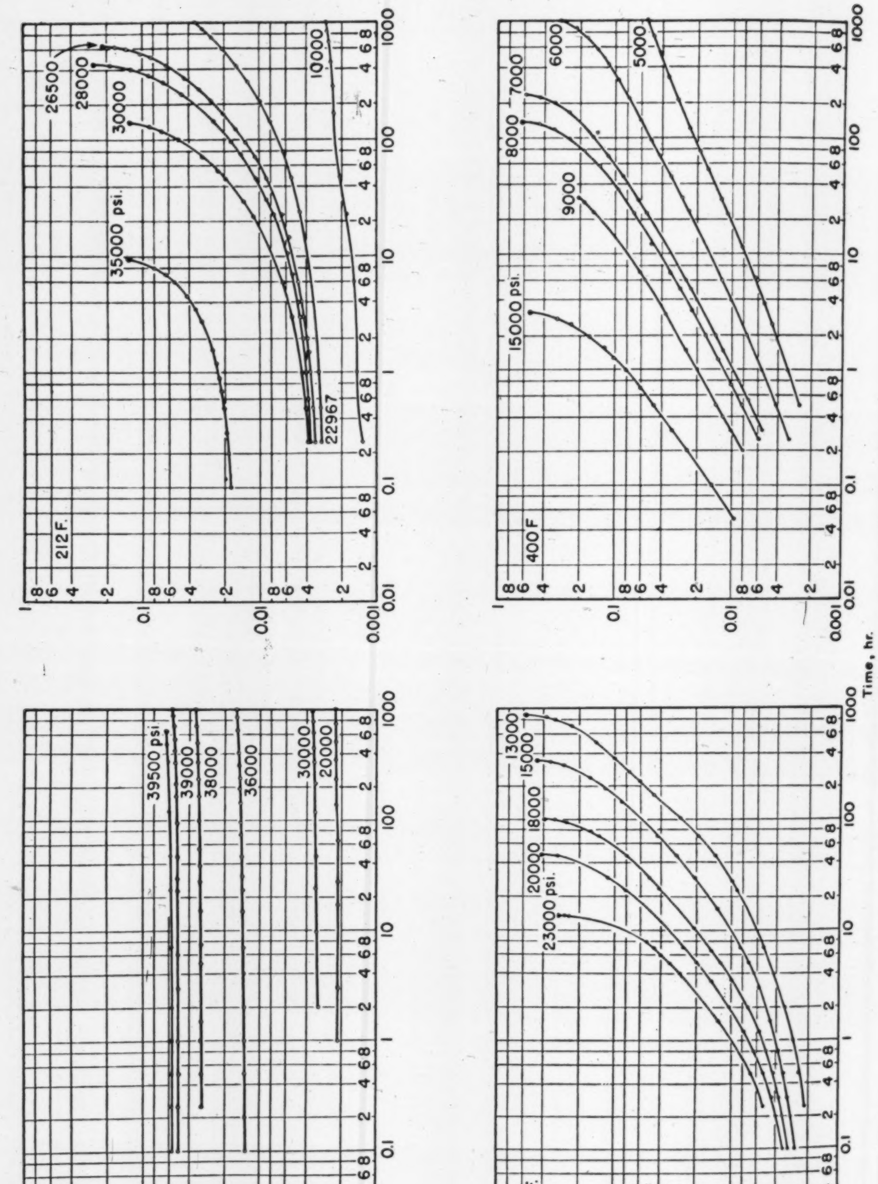


Fig. 4.—Total Creep Strain as a Function of Time for 52S-H38.

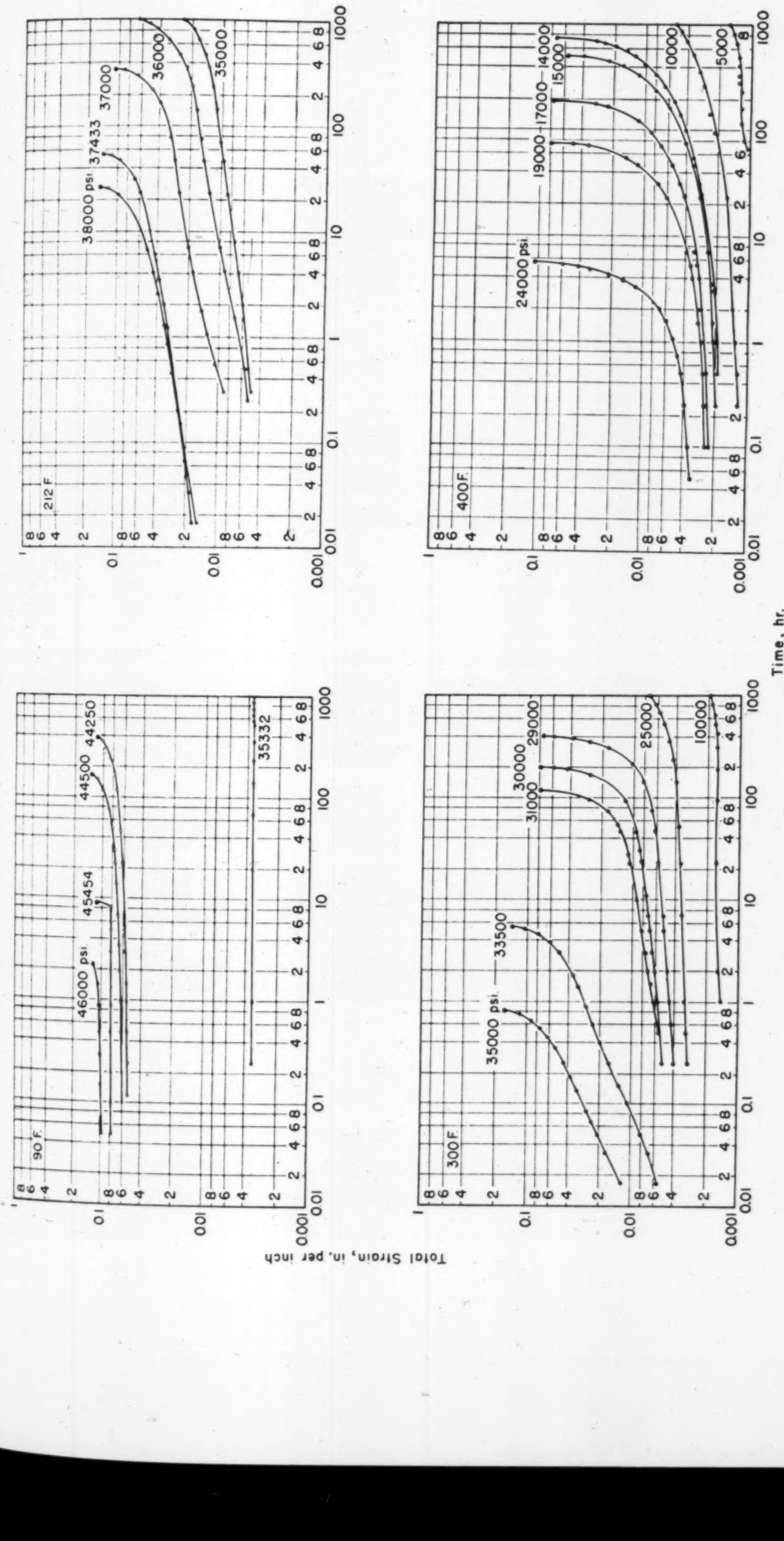


FIG. 5.—Total Creep Strain as a Function of Time for 61S-T6.

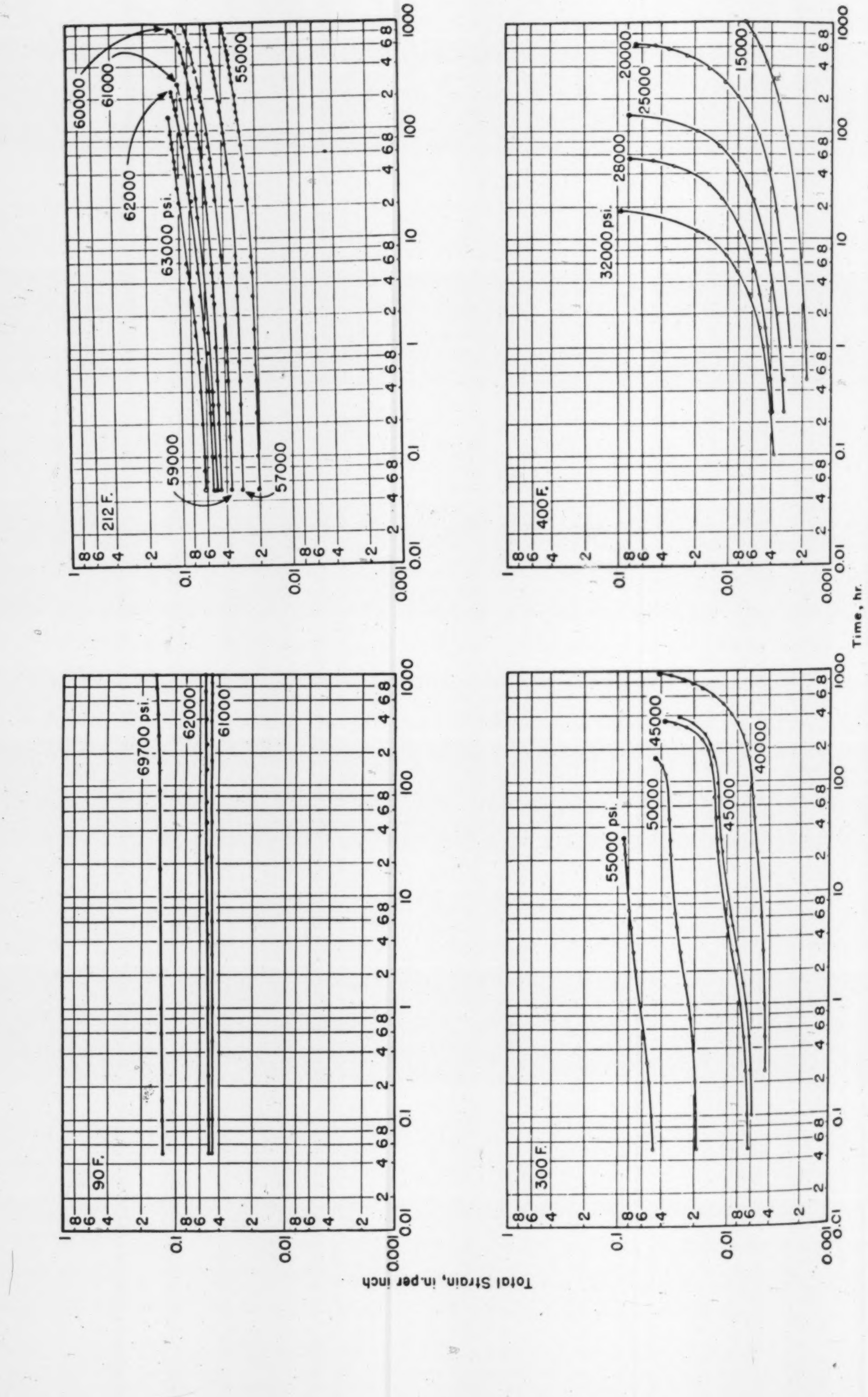


Fig. 6.—Total Creep Strain as a Function of Time for 24S-T3.

as a function of the logarithm of the time. Although this method of recording creep strains is somewhat unconventional, it has the advantage over the more common cartesian plots of permitting more rapid comparisons among the various temperatures and alloys which were investigated. The open circles represent the data during the course of the investigation and the solid point at the terminus of some of the curves is a fracture datum.

EVALUATION OF THE DATA

In order to ascertain some of the significant quantities for creep, all of the tests were also plotted in cartesian coordinates as illustrated in Fig. 7. The secondary creep rate over Stage II of the diagram was obtained by a graphical determination of the slope of the straight-line portion of the creep curve. Since some interest was expressed in the duration of the primary and secondary stages of creep, an attempt was made to determine the times at which the secondary and tertiary stages of creep are initiated. It was not always possible to do this with high accuracy because of the rather gradual transitions from one stage of creep to the next stage. Consequently, the data on the time of initiation of the secondary and tertiary stages are not believed to be highly accurate.

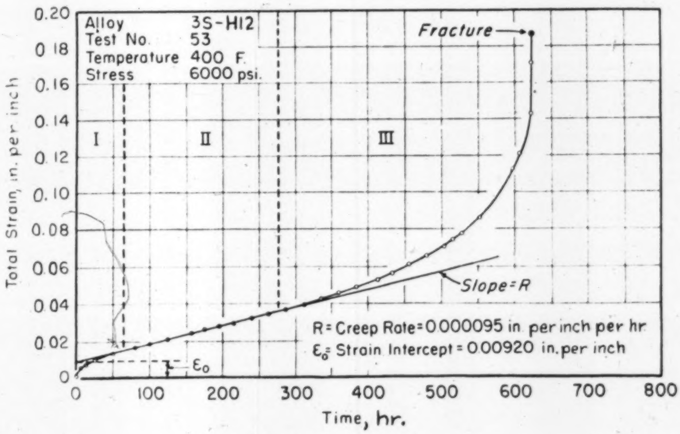


FIG. 7.—Typical Creep Curve.

DISCUSSION OF RESULTS

The effect of stress on the secondary creep rate and on the time to rupture are recorded in Fig. 8. In order to provide a rapid comparison of the secondary creep rate and the time to rupture for any given stress level, both the secondary creep rates and the times to rupture were plotted on the same chart, using the conventional logarithmic method of plotting.

It is interesting to note that the curves for 3S-H12, 3S-H18, 52S-H32, and 52S-H38 are almost linear. Plots for 61S-T6 and 24S-T3 at 212 F. and above are curved. Similarly curved creep and stress-rupture curves were obtained in the earlier investigations on precipitation-hardened aluminum alloys (1). Perhaps the differences between the two classes of alloys is associated with the absence of precipitation and overaging effects in the first group and the existence of these effects in the second group.

Alloy 61S-T6, having been artificially

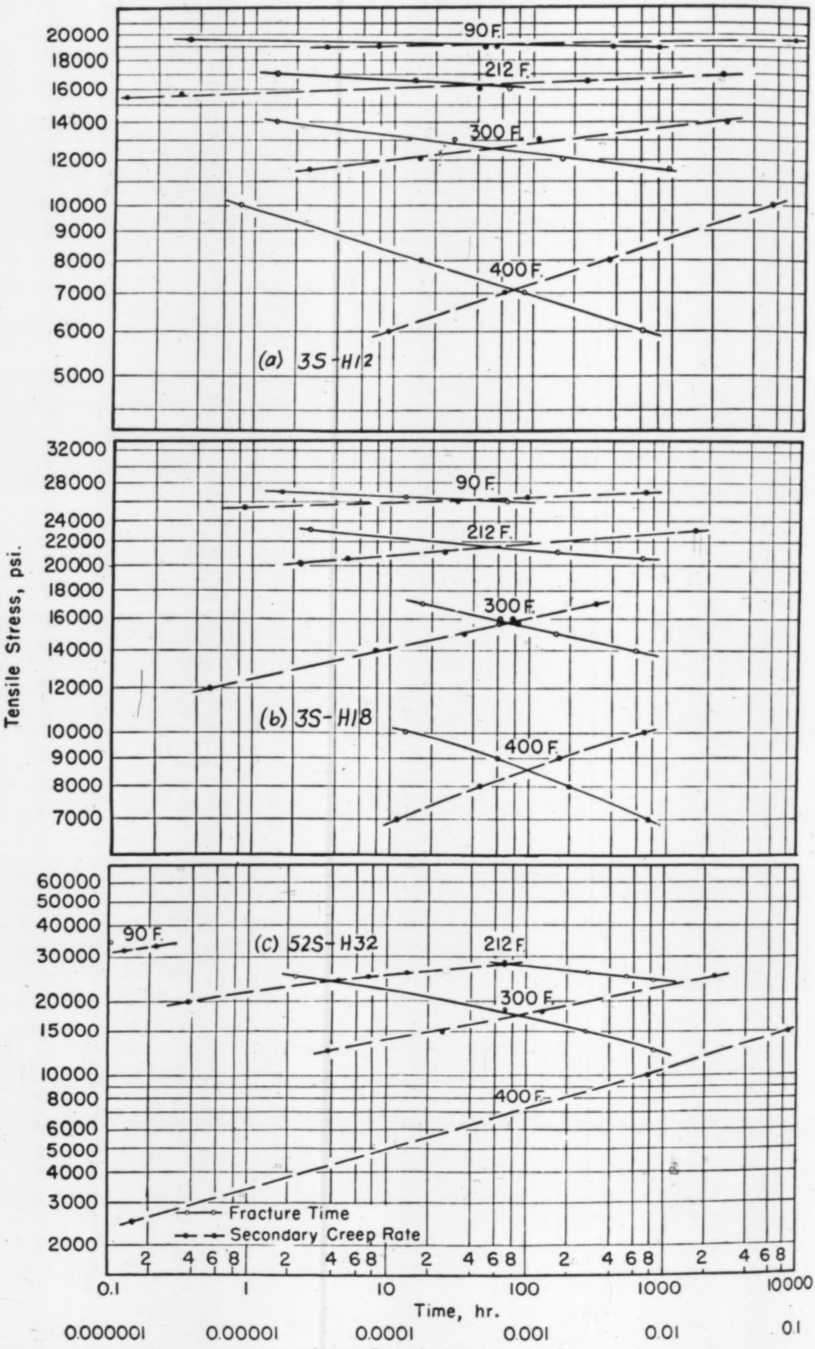
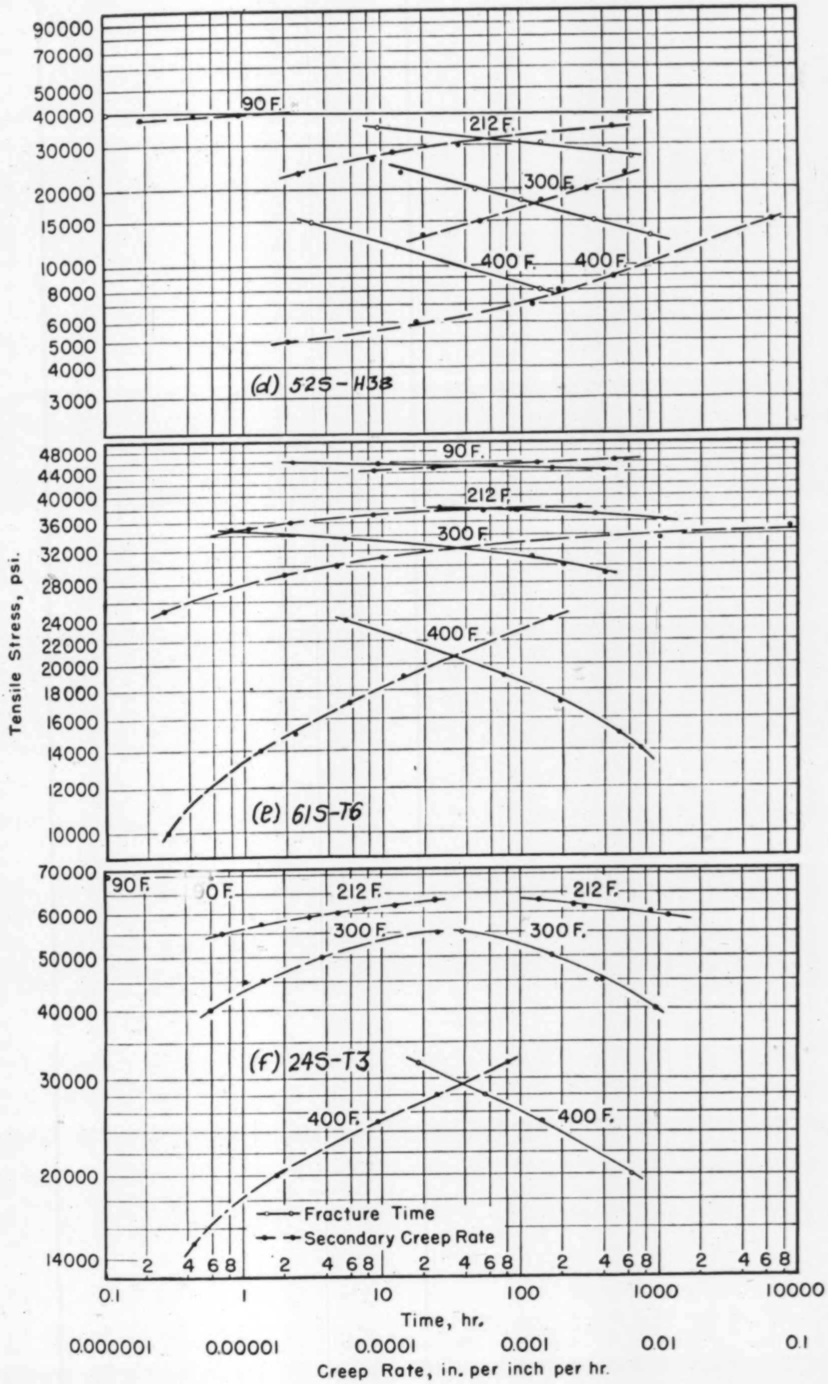


FIG. 8.—Secondary Creep



Rate and Stress Rupture.

aged at 345 to 355 F. for about 8 hr., is initially in a precipitation-hardened condition that provides about the maximum flow stress. Additional time at the elevated creep temperatures results in overaging and consequent reduction in the flow stress. At lower stress levels and, therefore, longer exposure times at the elevated temperatures before the secondary stage of creep begins, the metal becomes softer and therefore exhibits proportionately greater secondary creep rates. In this way, an explanation of the fact that the secondary creep curves for 61S-T6 are concave downward might be sought. Undoubtedly the creep strains also has an effect on the rate of overaging of the precipitation-hardened alloys.

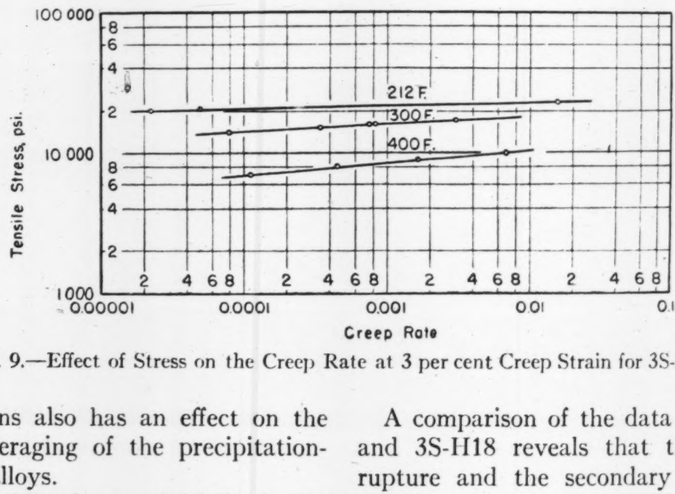


FIG. 9.—Effect of Stress on the Creep Rate at 3 per cent Creep Strain for 3S-H18.

Alloy 24S-T3 is not initially in its highest flow stress condition, and it will continue to precipitation harden at the elevated creep temperatures. For longer times at temperature, however, overaging will occur, the rate of precipitation hardening and overaging increasing with increasing temperature. In the short-time creep tests at high stress levels, therefore, the flow stress may have increased above its initial value and the secondary creep rate may therefore be lower than in the virgin alloy, whereas for lower stresses and therefore longer times, the flow stress is lowered below its value in virgin 24S-T3, and higher secondary creep rates are possibly obtained than would be obtained in virgin material. At about 300 F., in which region the effects of precipitation hardening are known to be pronounced, 24S-T3 creep data would be expected to deviate more severely from the linear relationship than the 61S-T6 data at the same temperature. The fact that it is so supports the validity of this hypothesis. But again in 24S-T3 alloys the effects of strain, as well as temperature, may affect the rate of precipitation hardening and overaging.

A comparison of the data for 3S-H12 and 3S-H18 reveals that the time to rupture and the secondary creep rate are substantially improved by cold rolling from the H 12 to the H 18 condition for all temperatures which were studied. A less pronounced improvement of the stress rupture and creep characteristics of 52S alloy as a result of cold rolling from the H 32 to the H 38 temper is also noted at 90 F. and 212 F. But at 300 and 400 F., there appears to be little difference between the creep characteristics of 52S in the two different cold-rolled tempers.

If a suitably accurate theory of creep were available which would permit an analytical correlation of the creep rate with the stress, temperature, and the total creep strain (or perhaps an effective creep strain), much time and effort in gathering creep data could be saved. Such a theory would permit predictions of the creep rate for all temperatures and stresses from a minimum number of tests.

Recently Zener and Hollomon (2, 3) proposed a simple expression for correlating the flow stress of metals with the strain, the strain rate, and the temperature. They suggested that

$$\bar{\sigma} = \bar{\sigma}\,(\bar{\varphi}, \dot{\bar{\varphi}} e^{\Delta H/RT}) \ldots\ldots\ldots (1)$$

where:

$$\sigma = \frac{L}{A} = \frac{L}{A_0}\frac{A_0}{A} = S\,\frac{A_0}{A} = S\,\frac{l}{l_0}$$

$$= S(1 + \epsilon) \qquad \text{(true stress)}$$

$$\bar{\varphi} = ln\; l/l_0 = ln\;(1 + \epsilon) \qquad \text{(true strain)}$$

$$\bar{\varphi} = \frac{\partial}{\partial t}\, ln\;(1 + \epsilon) \qquad \text{(true strain rate)}$$

ΔH = activation energy (cal. per mole),
R = gas constant (cal. per mole per deg.),
T = absolute temperature (deg. K),
e = base, natural logarithm,
L = instantaneous tensile load,
A = instantaneous cross - sectional area,
A_0 = initial cross-sectional area,
S = L/A_0 the engineering stress,
ϵ = $\frac{l - l_0}{l_0}$ the engineering strain,
l = instantaneous gage length,
l_0 = initial gage length, and
t = time

This relationship has been used to correlate the flow stress of metals with the strain-rate and temperature at constant strains over regions of temperature where recovery is not a complicating factor. More recently, however, Hollomon (4) suggested that this equation is also valid in the creep range of temperatures for materials that exhibit structural stability. It is interesting, therefore, to examine its validity for the tests investigated here.

Alloys 3S-H12 and 3S-H18 appear to be most suitable for this examination because of the indications of structural stability suggested by the linear relationship between the logarithm of the creep stress, S, and the logarithm of the secondary creep rate $\left(\frac{d\epsilon}{dt}\right)_s$. Undoubtedly Eq. 1 is invalid for 61S-T6 and 24S-T3 because they undergo precipitation and overaging phenomena which introduce another independent variable, namely, time at temperature.

A review of the creep data for 3S-H18 revealed that the creep rate at a strain of $\epsilon = 0.03$ was accurately evaluable for all stresses which were investigated at temperatures from 212 to 400 F. These data are recorded in Fig. 9, where it will be noted that

$$\log S = A + B \log \frac{d\epsilon}{dt} \ldots\ldots (2)$$

for each temperature. Therefore, by conversion to true stresses and true strain rates

$$\log \bar{\sigma} = \log\,(1 + \epsilon)$$
$$= A + B[\log \dot{\bar{\varphi}} + \log\,(1 + \epsilon)]$$

or since $\epsilon = 0.03$

$$\log \bar{\sigma} = A' + B \log \dot{\bar{\varphi}} \ldots\ldots (3)$$

where A' and B are functions of the temperature. But according to the dictates of Eq. 1, the temperature effect should be accounted for by

$$\log \bar{\sigma} = A' + B \log \dot{\bar{\varphi}}\, e^{\Delta H/RT}$$
$$= A' + B \log \dot{\bar{\varphi}} + B\,\frac{\Delta H}{RT} \log e$$

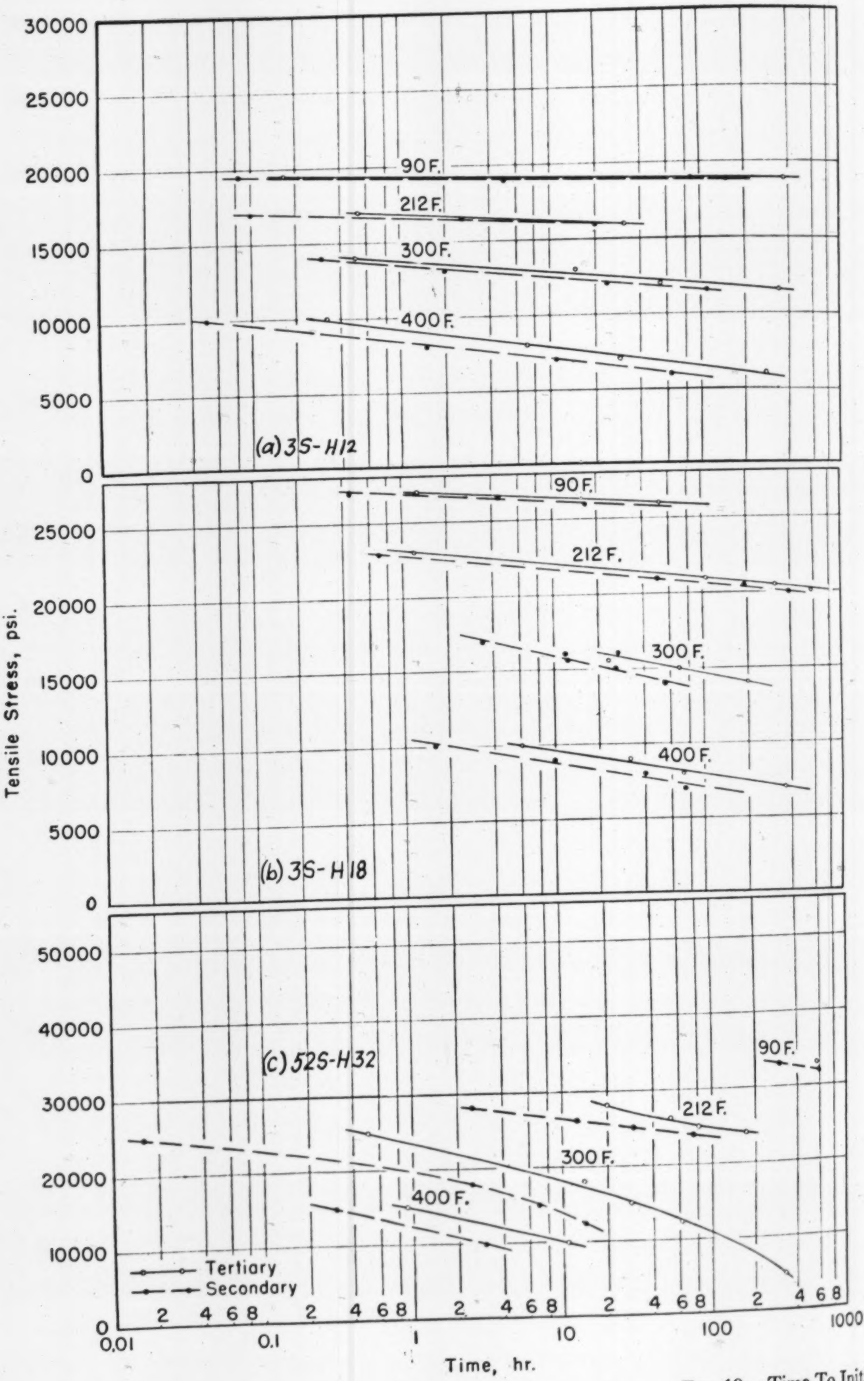
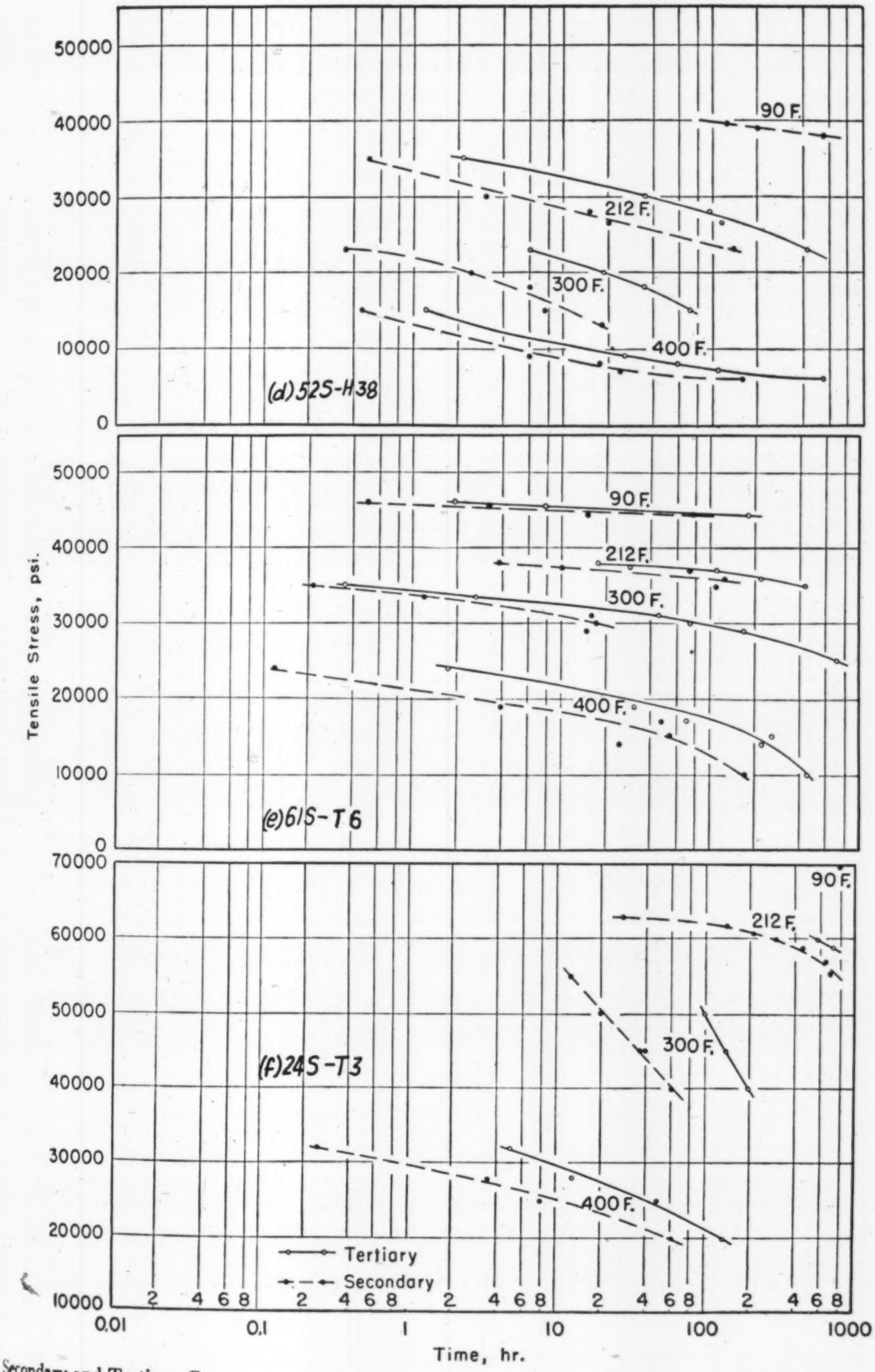


FIG. 10.—Time To Initiate



Secondary and Tertiary Creep.

where A' and B are constants independent of temperature. Since the slopes of the creep curves of Fig. 9 are different for each different temperature, it follows that Eq. 1 is not valid for the creep of 3S-H18 alloy. A similar analysis for 3S-H12 demonstrates that Eq. 1 is also invalid for this alloy. It is quite possible that the failures of Eq. 1 arise from softening of the work-hardened metal at the elevated creep temperatures and therefore the *effective* strain may not be 0.03 but some lower equivalent value. Although this is undoubtedly a contributing factor to the failure of Eq. 1 it is now known that Eq. 1 is invalid even at low temperatures where recovery is absent (5). There yet exists a need for fundamental studies on the creep of metals to elucidate more completely the processes occurring during creep in order to provide a reasonably accurate stress-strain-strain rate-temperature relationship for creep phenomena.

Time for Tertiary Creep:

In some applications, the time to rupture, as given in Fig. 8, is employed to designate the upper limit of useful life of a structural member subjected to conditions of creep. More recently, however, there has been a tendency among engineers to use a more conservative useful life, namely, that at which the tertiary stage of creep begins. The time for initiation of the third stage of creep is shown in Fig. 10. In addition, on the same charts are recorded the times at which the secondary stage of creep begins. Reference to Fig. 7 reveals that it is frequently difficult to ascertain with precision when the primary stage of creep enters the secondary stage or when the secondary stage of creep merges into the tertiary stage. For this reason, high precision is not guaranteed for the times recorded in Fig. 10.

CONCLUSIONS

1. The creep and stress-rupture characteristics of 3S-H12, 3S-H18, 52S-H32, 52S-H38, 61S-T6, and 24S-T3 alloys were studied from 90 to 400 F. for times up to 1000 hr.

2. Alloy 24S-T3 exhibited the best resistance to creep and stress rupture, and 61S-T6 was second best among the alloys which were tested.

3. The order of resistance to creep and stress-rupture among the cold-rolled metals was 52S-H38 (best), 52S-H32, 3S-H18, and 3S-H12 (lowest). Little difference, however, was noted between 52S-H32 and 52S-H38 at 300 F. and 400 F.

4. Cold rolling appears to improve the creep and stress-rupture resistance of the work hardenable alloys.

5. The relationship between the flow stress, strain, strain rate and temperature $\bar{\sigma} = \bar{\sigma}\,(\bar{\varphi}, \dot{\bar{\varphi}}\, e^{\Delta H/RT})$ is invalid for the materials investigated here.

Acknowledgment:

The authors wish to acknowledge the sponsorship of this investigation by the Aluminum Company of America as part of its program of investigations on the effect of temperature on the properties of aluminum alloys. They especially wish to thank R. L. Templin for the many excellent suggestions he made throughout the course of these investigations. In addition, they thank E. Berliner for his careful and accurate assistance in conducting the tests and also C. H. Avery, C. Elson and R. A. Anderson for their aid in the reduction of the data and preparation of the curves.

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DISCUSSION

Mr. M. J. Manjoine.[1]—The authors have expressed the fact that present theories of creep are inadequate to explain their results. This is unfortunately true because of the many factors involved, such as the metallurgical changes which take place during these tests.

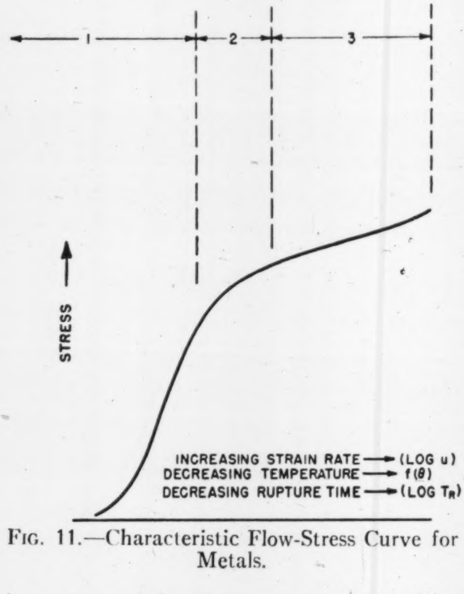

Fig. 11.—Characteristic Flow-Stress Curve for Metals.

However, in the effort to get a more general expression for the flow of a metal, the characteristic flow-stress curve is presented in the accompanying Fig. 11. This curve expresses the flow stress at a given strain as a function of strain rate, temperature, or rupture time. In the first region, 1, the stress can be expressed in most cases by the hyperbolic sine law. In the second region, 2, the effects of a metallurgical change are taken into account. This change may be precipitation, as noted for the alloys in this paper, or may be annealing, the effect of which increases toward the left as longer times are available. In the third region, 3, the stress is practically a logarithmic function of the rate. This range also represents those tests at lower temperatures where precipitation or annealing occur too slowly to affect the strength.

In the tests described in this paper the temperature range is such that the flow condition changes from region 3 to region 1. We cannot, therefore, expect one flow law to cover all the tests since these alloys act like different materials at the various temperatures or, in some cases, at the various stresses. Any theory which does not take into account this change in the material will not, of course, express the flow condition.

This diagram is, therefore, presented to show that if tests are made on materials which undergo these changes, then the theory of flow must be so general as to take these factors into account.

Mr. G. R. Gohn.[2]—I should like to add to what Mr. Manjoine has said that the laws governing creep are further complicated if you have recrystallization occurring during any one of the three stages of creep. Generally, this recrystallization has not been observed in the materials which we have studied, but Greenwood and his coworkers have shown that there is a very marked change in creep rate during recrystallization so that we have to add this additional factor to those which Mr. Manjoine has discussed. (Some of this work has been published in recent English publications.)

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[1] Research Engineer, Mechanics Dept., Westinghouse Research Labs., Westinghouse Electric Corp., East Pittsburgh, Pa.

[2] Member of Technical Staff, Bell Telephone Laboratories, Inc., New York, N. Y.

The authors have stated two points which I should like to emphasize: first of all, there is no common law which will apply to the entire range of creep. Usually, there are three different stages of creep and no one law appears to fit all three. Many authors and students of the creep-behavior of metals over-simplify the problem by developing one equation to fit the entire time-extension curve. This just cannot be done.

The other point which I should like to emphasize is a statement by the authors that, today, we are placing more emphasis on creep rate data and the beginning of the tertiary stage of creep than on stress-rupture data. When I first got into creep testing, everybody was studying the stress-rupture curves, trying to extrapolate these curves and develop a formula for calculating the minimum stress at which no rupture would occur. Well, obviously, from an engineering standpoint, in most cases the usefulness of the alloy has ceased long before rupture occurs. This is now being recognized and there is increasing emphasis on obtaining the minimum or steady creep rate and some indication as to the period of time during which that rate will hold. From these data one can predict, with reasonable factors of safety, the useful life of the equipment which is being designed. I am very happy to see that the authors have stressed this point in their discussion.

MESSRS. J. E. DORN AND T. E. TIETZ (*authors' closure*).—The authors wish to thank Mr. M. J. Manjoine and Mr. G. R. Gohn for their pertinent contributions to this paper. They concur heartily with the theses of both Messrs. Manjoine and Gohn that structural changes which occur during creep preclude the possibility of the validity of any theory which neglects such factors. Recent unpublished investigations conducted in the metallurgy laboratories of the University of California have clearly shown that the properties and, therefore, the structure is changing even over the secondary stage of creep in such a way that the amount of strain hardening is greater at the conclusion of the secondary stage than just after the initiation of the secondary stage. This fact further emphasizes the comments of Messrs. Manjoine and Gohn.

THE INFLUENCE OF VIBRATION ON THE CREEP OF LEAD*

By J. Neill Greenwood[1]

Synopsis

Creep tests on two industrial leads (both very pure) and two lead alloys, one containing 0.027 per cent silver and the other 0.07 per cent copper have been made under conditions whereby a gentle 50 cycles per second vibration was superposed on direct tensile stress. The stresses were between 100 and 350 psi.

It is shown that vibration increases the rate of creep and also accelerates the recrystallization under stress. During recrystallization, the creep rate increases considerably. Without vibration, the industrial lead (U) will recrystallize after an extension of 4 to 5 per cent, whereas, with the vibration superposed, this will occur after 2.5 per cent extension. The grain size increases considerably during this process.

The effect of silver on the over-all creep rate under vibratory conditions, is, in general, negligible, though in detail it seems evident that the creep characteristics of the alloy are quite different from those of the basis lead. It is shown that in a certain condition the creep rate of lead can be *increased* by the presence of silver.

The effect of copper is affected by the degree of dispersion. Finely dispersed copper considerably lowers the creep rate of the basis lead while a coarser degree of dispersion leaves the creep rate unchanged.

Both silver and copper reduce the susceptibility of lead to recrystallize under stress, at least up to 15 per cent extension.

Annealing lead at 120 C. (250 F.) for 24 hr. stabilizes the crystal grains in some way, reduces the creep rate under given conditions, and reduces the susceptibility to recrystallization under stress.

Previous Work

In a series of papers (**1–8**)[2] the author and his colleagues have given the results of their experiments on the influence of stress on the creep rate of lead and its dilute alloys with Ca, Mg, Zn, Cu, Ag, Te, Sb, and Bi respectively.

More recently, more detailed work has been reported (**9–12**) on the influences of stress and temperature on the creep rate of pure lead, 0.03 per cent silver lead, 0.07 per cent copper lead, and 0.05 per cent calcium lead.

It has been shown that there is a general type of curve (Fig. 1) which expresses the relationship between stress and creep rate after a given time (or total creep after a given time). This type of curve, known in America as the McVetty type curve, has been styled by the author, (**10**) a creep yield curve and a special significance has been given to the two

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[*] Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] Research Professor of Metallurgy, Baillieu Laboratory, University of Melbourne, Australia.

[2] The boldface numbers in parentheses refer to the references appended to this paper, see p. 850.

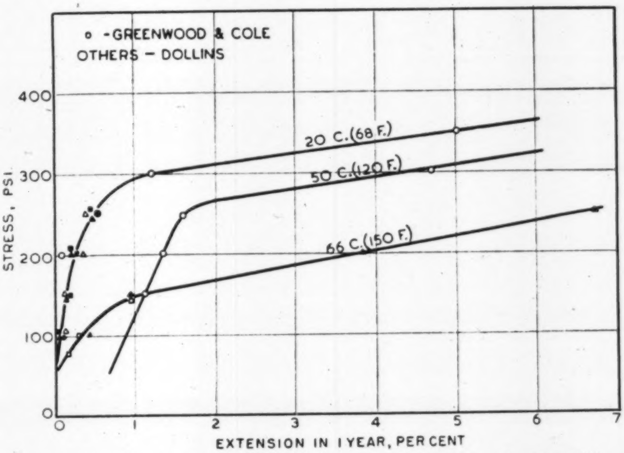


FIG. 1.—Creep Yield Curves for Several Industrial Leads Under Static Conditions (American and Australian Results).

branches of the curve. Below the knee of the curve—the creep yield stress—it is considered that the stress affects chiefly the boundary zone of the crystal, while above this stress it is thought that deformation occurs, as well, in the body of the crystal itself. It is further considered that this stress is a fundamental characteristic to be determined for each alloy, and that design stresses should be kept below this value. The sharp increase in the creep rate above the creep yield stress is partly due to the increased volume of material taking part in the movement, and partly due to a new mechanism of deformation which comes into operation.

From Fig. 1 it will be seen, as would be expected, that the creep yield stress is affected by temperature. The results incorporated in that figure are partly from the author's laboratory and partly from the Illinois Engineering Experiment Station (C. W. Dollins (13)).

For the sake of completeness the stresses which give 1 per cent stretch in 1 yr. at various temperatures for pure lead, 0.07 per cent copper lead, and 0.02 to 0.05 per cent calcium lead are given in Fig. 2 (12). The importance of data of this type cannot be overestimated in connection with design.

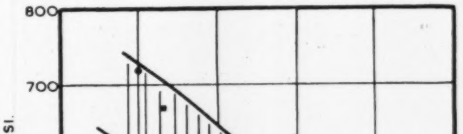


FIG. 2.—Stress (Static) to Cause 1 per cent Extension in 1 yr. for Various Leads at Different Temperatures. (American and Australian Results).

Another important result reported in previous work is that lead will undergo spontaneous recrystallization under stress, and at the time of this change the creep rate considerably increases. Hence a marked deviation is obtained in the strain-time curve (constant load) similar to that shown in curve *B* of Fig. 3. The difference in the nature of these two curves is brought out more strongly if they are plotted as in Fig. 4, in which strain and strain rate are the coordinates.

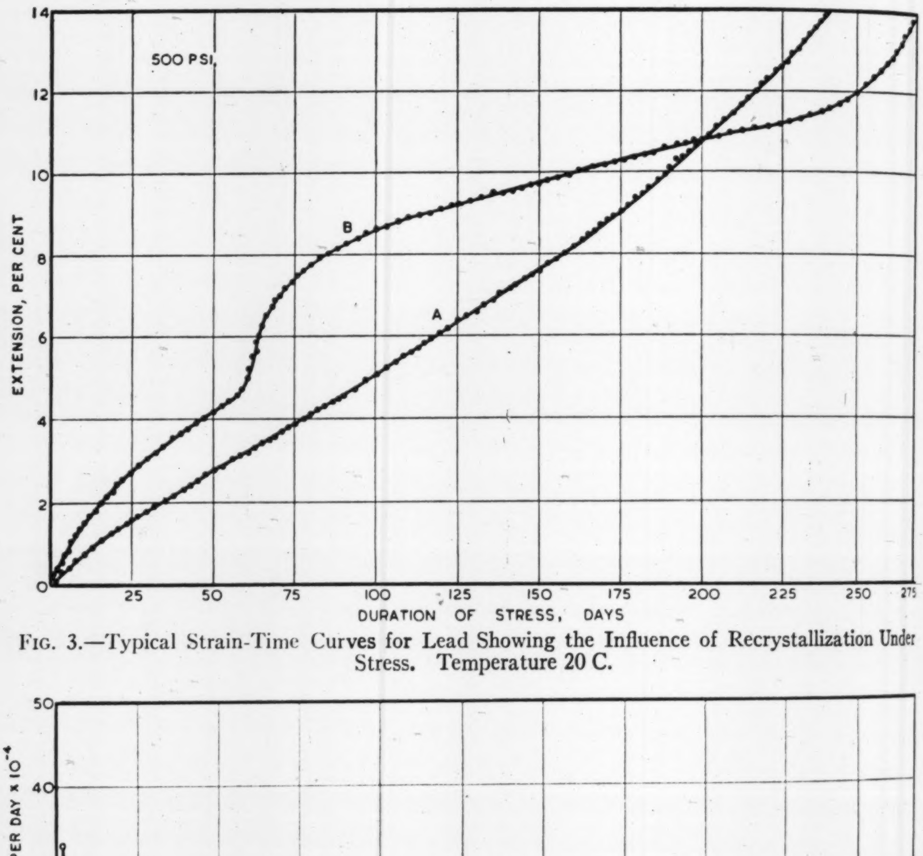


FIG. 3.—Typical Strain-Time Curves for Lead Showing the Influence of Recrystallization Under Stress. Temperature 20 C.

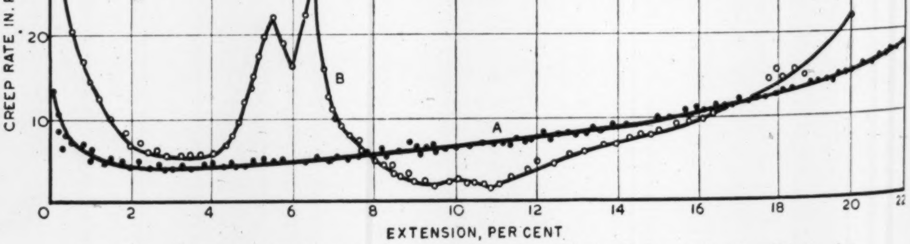


FIG. 4.—The Same Data as in Fig. 3 Plotted as Rate of Creep Against Extension.

The two curves in this figure were obtained with two different industrial leads in the same condition under 500 psi. stress after annealing 100 C. for 15 min. In curve *A*, a marked fall in rate of creep, as stretching progressed, is noted—a minimum value is reached after which the rate slowly increased again and, ulti-

TABLE I.—DESCRIPTION OF TEST SPECIMENS.

Series	Type of Lead	Condition	Stresses Applied, psi.						Grain Size, mm.
1	SA	Annealed at 100 C. for 15 min.	50	100	200	250			0.5 to 1.5
2	SA	Annealed at 125 C. for 24 hr.	50	100	200				
3	U	Annealed at 100 C. for 15 min.	50	100	150	200	250	350	0.2 to 1.2
4	U	Annealed at 125 C. for 24 hr.	50	100	200	350			
5	Ag	Annealed at 100 C. for 15 min.	100	200	350				0.02 to 0.2
6	Ag	Annealed at 125 C. for 24 hr.	100	200	350				
7	Ag	Billet annealed at 250 C. for 40 hr. Test specimen annealed at 100 C. for 15 min.	100	200	350				0.05 to 0.15
8	Cu	Annealed at 100 C. for 15 min.	100	250	350				0.05 to 0.5
9	Cu	" " 125 C. for 24 hr.	100	200	350				
10	Cu	Billet annealed 250 C. for 40 hr. Test specimen annealed at 100 C. for 15 min.	100	200	350				0.15 to 0.25

mately, fracture occurred. In the case of curve *B*, after reaching a minimum value, the creep rate suddenly increased, reached a maximum, and then fell to a minimum rather lower than the previous one, thereafter following the usual path to fracture. It has been found that more than one such peak may occur during a complete test. The purer the lead the more clearly is this phenomenon observed. The deviation on the strain-time curve, or the strain-creep rate curve, is associated with a recrystallization of the test specimen. This starts from centers and spreads throughout the whole specimen (1). The new grain size is invariably larger than the original (which in most cases was of the order of 0.5 to 2.0 mm. in diameter) and in some cases the new crystals revealed by macro etching were 15 to 20 mm. long by 5 to 10 mm. wide. After such a change the creep rate fell to a lower value than that of the previous minimum, presumably due to the larger grain size.

CREEP TESTS WITH SUPERPOSED 50 CYCLE VIBRATION

In all the tests which had previously been carried out by the author, care had been taken to avoid vibration and shock. Although indication of intercrystalline cracking had been found in the quiescent tensile creep tests, it was not so extensive as that which is so frequently observed in the failure of lead sheeting in industrial plant. It was thought, therefore, that the imposition of a 50 cycle vibration would simulate more closely the industrial conditions, and this series of tests was inaugurated more with the object of exploring the effect rather than to obtain a complete answer to the influence of vibration.

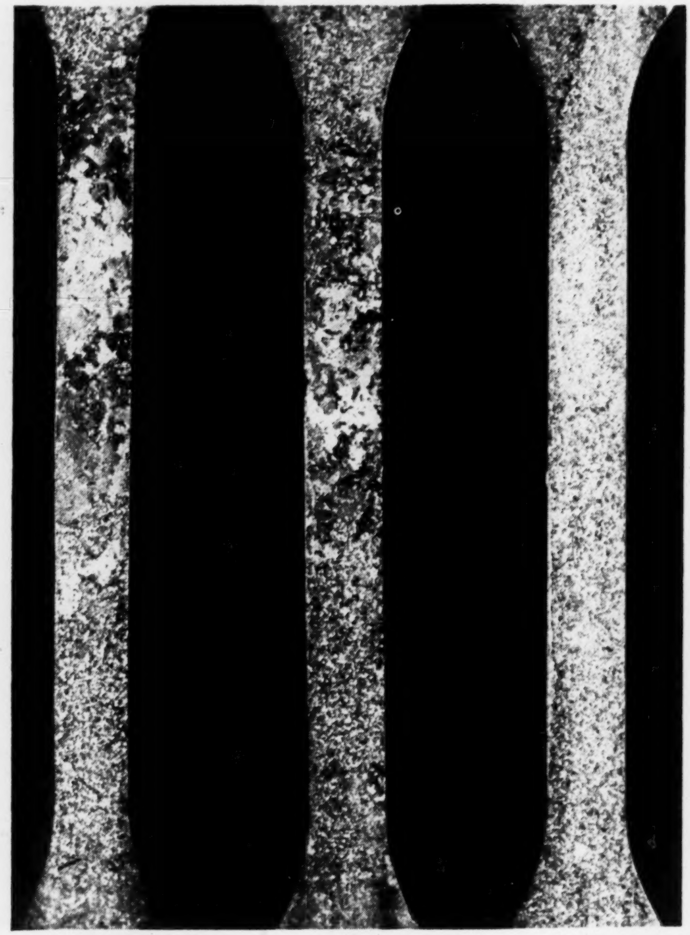
TABLE II.—ANALYSES OF TYPES OF LEAD TESTED.

Element, per cent	SA Lead	U Lead	Ag Lead	Cu Lead
Copper	0.0001	0.0002	....	0.075
Silver	0.0000	0.0003	0.027	....
Zinc	0.0002	0.0005	....	....
Bismuth	0.0007	0.0023	....	....
Antimony	0.0005	0.0042	....	....
Arsenic	nil	nil	....	....
Iron	0.0006	0.0007	....	....
Sulfur	0.0001	0.0004	....	....

Description of Test Specimens:

The tests fall into ten series, partly distinguished by the composition of the lead or alloy, and partly by the treatment given. The description of the several series is given in Table I, and the analyses for impurities and alloying elements are shown in Table II.

The alloys Ag and Cu were made from U lead as a base. The ingots were cast into a mold 1 by 1 by 6 in. After removing the wrinkled surface by shaping, they were, in general, rolled to strip $\frac{1}{8}$ in. thick. In the case of the copper and silver lead alloys, as well as the direct rolling mentioned, another set of test specimens was prepared from material which had a prolonged homogenizing anneal after the ingot had been reduced 25 per cent. This anneal was for 40 hr. at 250 C. followed by water quenching and has been called a "billet" anneal. Its purpose was to allow coalescence of the copper particles in the copper alloy and to take the silver into solid solution in the case of the silver alloy. The billet



(a) (b) (c)

FIG. 5.—Recrystallization of U Lead Under Stress. Test Specimens Re-etched After 11 yr.

(a) Stress 250 psi. Total Extension 8.4 per cent.
(b) Stress 200 psi. Total Extension 3.7 per cent.
(c) Stress 150 psi. Total Extension 1.6 per cent.

after this treatment was rolled to $\frac{1}{8}$-in. strip. The actual tests were started one month later.

All specimens, before loading, received one of two treatments:

(*a*) Annealing for 15 min. at 100C., called "basic" anneal, or
(*b*) Annealing for 24 hr. at 125C., called "stabilizing" anneal.

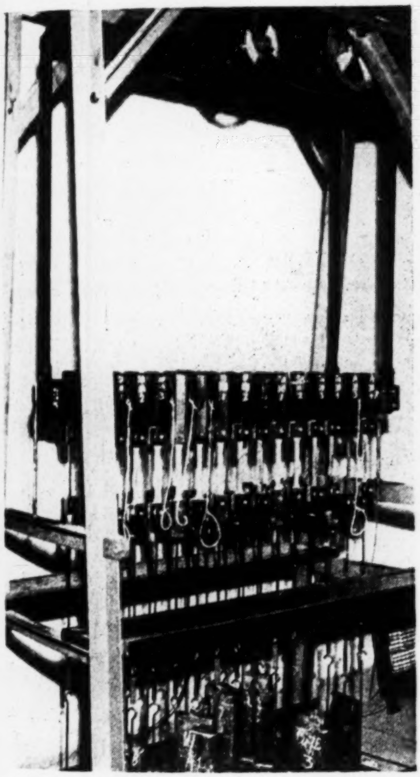


FIG. 6.—Equipment for Making Tensile Creep Tests Under Vibratory Conditions.

It had previously been found that for the alloys used, treatment (*a*) removed cold work effects, while treatment (*b*) tended to stabilize the crystal boundaries, that is boundary migration was minimized.

The grain size of the specimens after these various treatments is given in the last column of Table I.

The specimens were cut from the 1.5-in. wide strip by supporting in a jig and reducing the width at the gage length to 0.5 in. with a 2-in. radius shoulder (see Fig. 5).

To measure the strain, chromium-plated brass strips were soldered to each end of the 100-mm. gage length in such a way that they lay alongside each other, overlapping about the center of the test specimen. A fine line was scribed across these two strips and a Cambridge measuring microscope was used to read the distance apart of the lines as the specimen extended. The strain could be read directly to 0.005 mm.

The Straining and Vibrating Equipment:

The general assembly of the test bench is shown in Fig. 6. The saddles carrying the specimens were each suspended on a 5-mm. ball for self alignment. There were 14 specimens on each of two steel bars 4 in. by 0.5 in. in cross-section. The two bars were connected at the ends by welded cross pieces and the whole system was suspended through springs from a platform on which was mounted a disk rotated at 3000 rpm. by a 0.25-hp. motor through a V-belt drive. When readings were to be taken, the motor was stopped and the suspension bars were clamped to the framework. Each specimen was stressed through a small spring by a direct load.

The rotating disk conveyed a 50 cycle vibration with a vertical component which had an amplitude of 0.05 to 0.13 mm. This vibration was quite complex, and no significance is to be placed quantitatively on either the frequency or the amplitude. These experiments must be considered as a qualitative exploration of the type of influence which vibration in general might have.

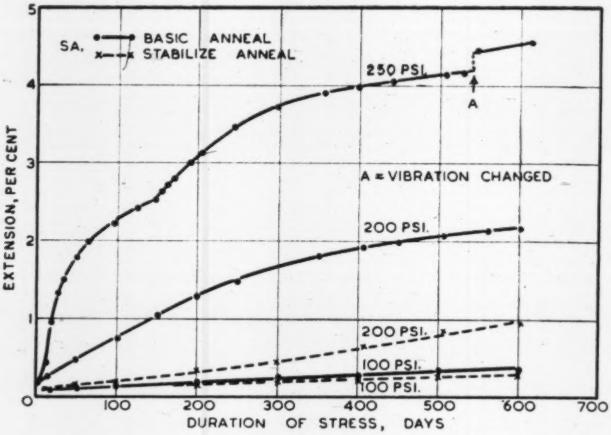


FIG. 7.—Total Strain-Time Curves for SA Lead in the Basic Annealed Condition and in the Stabilizing Annealed Condition.

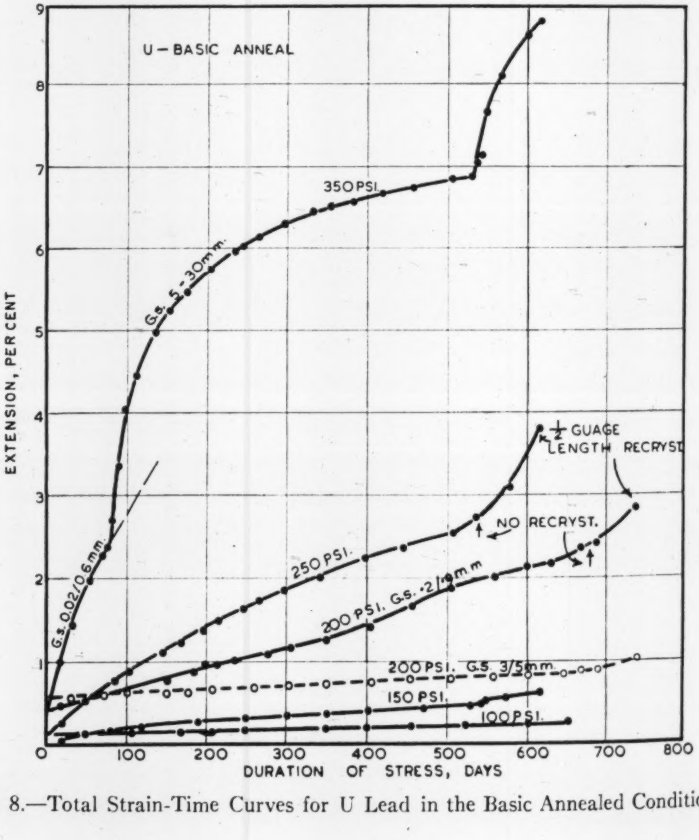


FIG. 8.—Total Strain-Time Curves for U Lead in the Basic Annealed Condition.

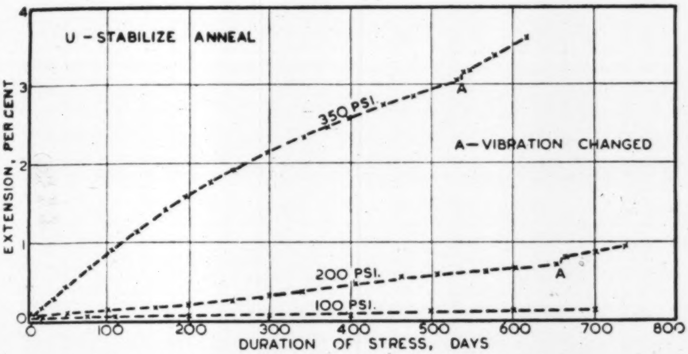


FIG. 9.—Total Strain-Time Curves for U Lead in the Stabilizing Annealed Condition.

TABLE III.—COMPARISON OF CREEP RATES OF SA LEAD WITHOUT AND WITH VIBRATION.

(Annealed 100 C for 15 min.).

Stress, psi.	Elongation, per cent			
	Without Vibration		With Vibration	
	After 1 yr.	After 2 yr.	After 1 yr.	After 2 yr.[b]
100	nil[a]	nil[a]	0.26	0.45
150	0.09	0.15	0.8[a]	1.5[a]
200	0.45	0.64	1.8	2.3
250	0.72	1.05	3.9[c]	4.4[c]
300	2.30	3.08	....	....
350	5.6[c]	7.6	....	....

[a] Estimated.
[b] Extrapolated from 600 days.
[c] Recrystallized during test.

TABLE IV.—INFLUENCE OF VIBRATION ON RECRYSTALLIZATION UNDER STRESS.

Stress, psi.	Elongation Causing First Recrystallization, per cent			
	SA lead		U lead	
	Without vibration	With vibration	Without vibration	With vibration
200....	...	...	...	2.5
250....	...	0.4 (2.2)[a]	...	2.8
300....	3.3	...	greater than 4.6[b]	...
350....	3.2	...	4.8	2.5 (6.9)[c]

[a] Actually noticed at 2.2 per cent but indications are that recrystallization occurred much earlier as no slip lines formed on original grains.

[b] This had not recrystallized when the test was terminated after 9½ yr. under stress.

[c] A second marked deviation in the curve indicated a second recrystallization.

TABLE V.—COMPARISON OF CREEP RATES OF U LEAD WITHOUT AND WITH VIBRATION.

(Annealed 100 C for 15 min.).

Stress, psi.	Elongation, per cent			
	Without Vibration		With Vibration	
	After 1 yr.	After 2 yr.	After 1 yr.	After 2 yr.[b]
100.......	....	....	0.2	0.27
150.......	....	....	0.38	0.6
200.......	0.2	0.35	1.3	2.8[a]
250.......	0.4	0.95	2.08	5.4[a]
300.......	1.15	1.9	....	....
350.......	6.0[a]	9.4	6.4[a]	9.4

[a] Recrystallized during test.
[b] Extrapolated from 615 days.

TABLE VI.—INFLUENCE OF HEAT TREATMENT ON CREEP RATE OF LEAD UNDER VIBRATORY CONDITIONS.

Stress, psi.	SA lead		U lead	
	100 C. for 15 min.	125 C. for 24 hr.	100 C. for 15 min.	125 C. for 24 hr.
100.......	0.27	0.2	0.2	0.08
200.......	1.8	0.55	1.3	0.4
250.......	....	....	2.1	....
350.......	....	....	6.5	2.45

TABLE VII.—COMPARISON OF CREEP RATES OF 0.027 PER CENT SILVER LEAD WITHOUT AND WITH VIBRATION.

(Annealed 100 C. for 15 min.).

Stress, psi.	Elongation, per cent			
	Without Vibration		With Vibration	
	1 yr.	2 yr.	1 yr.	2 yr.
200.......	0.48	0.8	1.1	2.0
350.......	5.0	10.9	6.0	13[a]

[a] By extrapolation from 615 days.

DISCUSSION OF RESULTS

No adequate tabulation of the results is possible, so these have been expressed in diagrammatic form in Figs. 7 to 15.

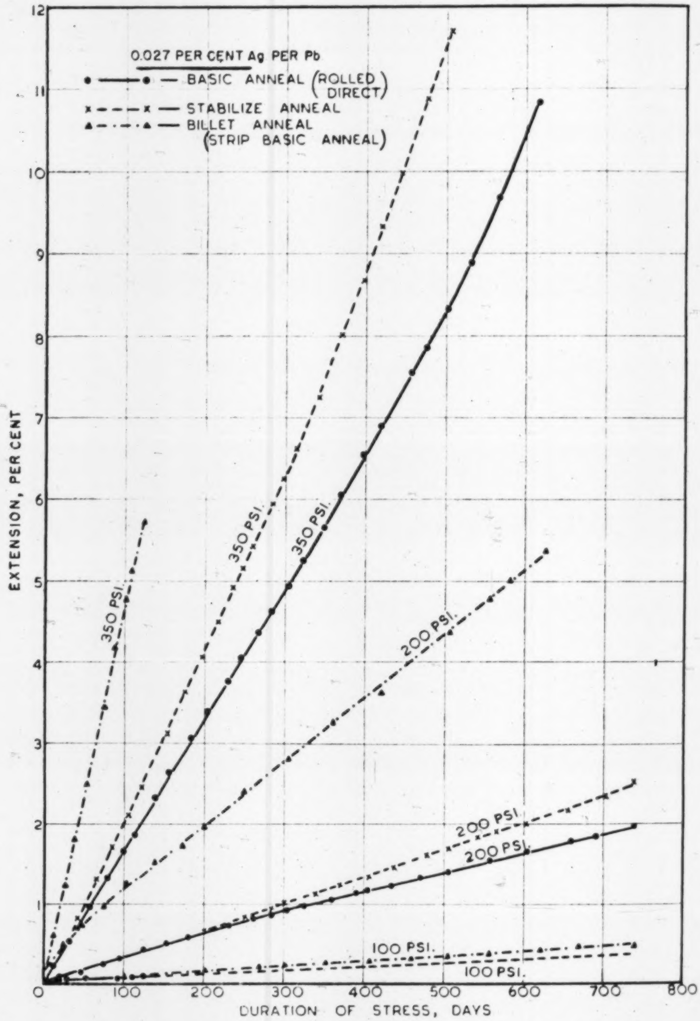


FIG. 10.—Total Strain-Time Curves for 0.027 per cent Silver Lead: Basic Annealed (Rolled Direct from the Ingot); Stabilizing Annealed Condition (Rolled Direct From the Ingot); and Basic Annealed (Billet Annealed 250 C. During Rolling Operations).

There are two bases for comparison:

(*a*) Each lead or alloy can be compared under a similar range of stresses without and with vibration.

(*b*) The various leads can be compared with each other under similar conditions of stress and vibration.

Both methods have been adopted.

Influence of Stress on SA Lead:

As shown in Table II this is a very pure industrial lead. The results for this are plotted in Fig. 7 and some comparative results are given in Table III.

It will be seen that vibration causes a considerable increase in the creep rate and that this is more marked at the lower stresses. For example, at 150 psi. there is a tenfold increase in rate while at 200 and 250 psi. there is a fourfold increase. Also the indications are that with the measuring system used, no creep would have been observed at 100 psi. without vibration, whereas with vibration, the corresponding figure (in both cases obtained by extrapolation) would be 50 psi.

A further influence of vibration is that it more readily causes recrystallization under stress. In Table IV are given the elongations before recrystallization was observed.

Without vibration, this lead in the basic annealed condition recrystallized under stress after 3.3 per cent elongation.

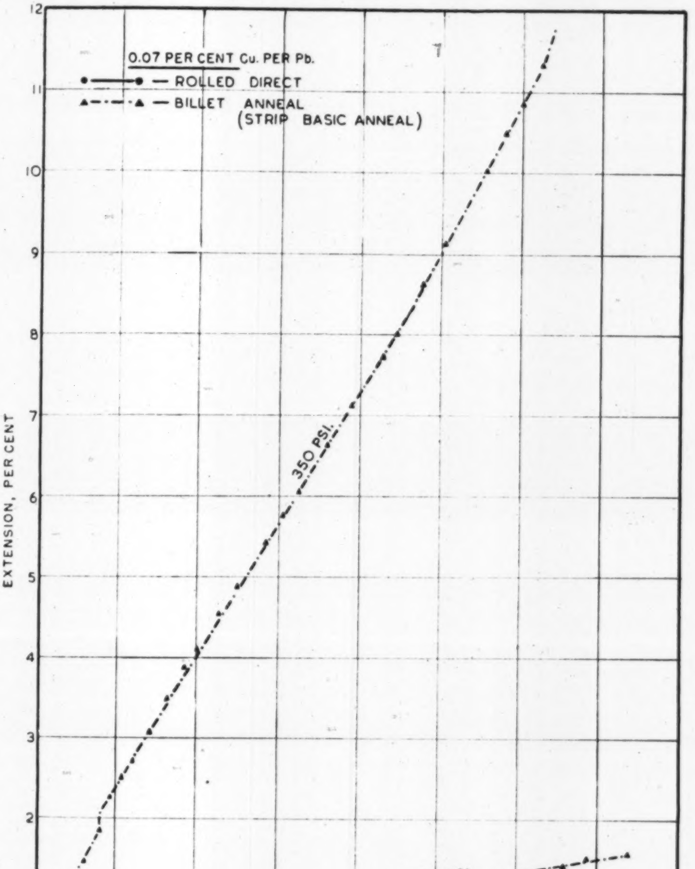


FIG. 11.—Total Strain-Time Curves for 0.07 per cent Copper Lead: Rolled Direct from the Ingot, and Billet Annealed 250 C. During Rolling Operations. Final Strip Basic Annealed in Both Cases.

With vibration, recrystallization was observed by the slip line system after 2.2 per cent. It is probable, however, from the shape of the curve, and from the fact that slip lines were not noticed on the original etched grains but only on the much larger crystals, that the recrystallization occurred very early—after only 0.4 per cent. When re-etched after 2.5 per cent elongation, the crystals which had originally been of an average diameter of 1 mm. were now found to be 30 by 5 to 10 mm.

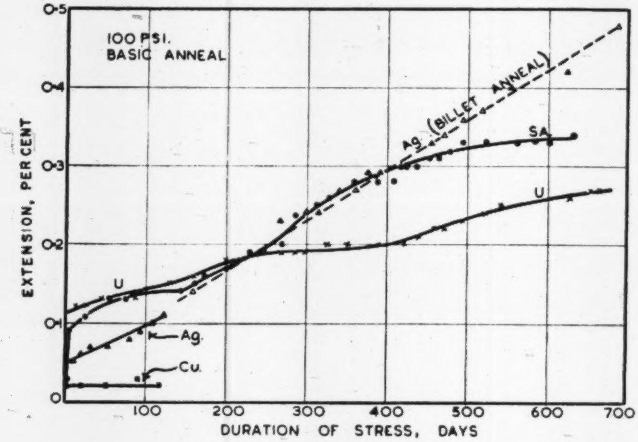


FIG. 12.—Total Strain-Time Curves, Stress 100 psi., Strip Basic Annealed.

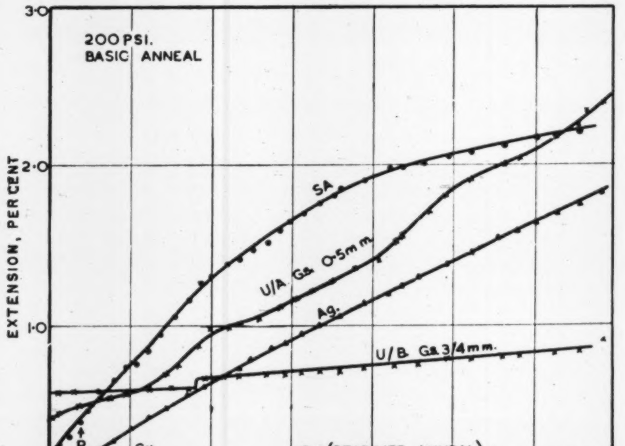


FIG. 13.—Total Strain-Time Curves, Stress 200 psi., Strip Basic Annealed.

The influence of the stabilizing anneal (24 hr. at 125 C.) is seen in Table V. The lower creep rate in this condition is usual for pure leads. Also it is unusual for lead to recrystallize under stress after this treatment, although in this case no test specimen was left long enough to check this point. Evidence was obtained, however, with U lead (see later).

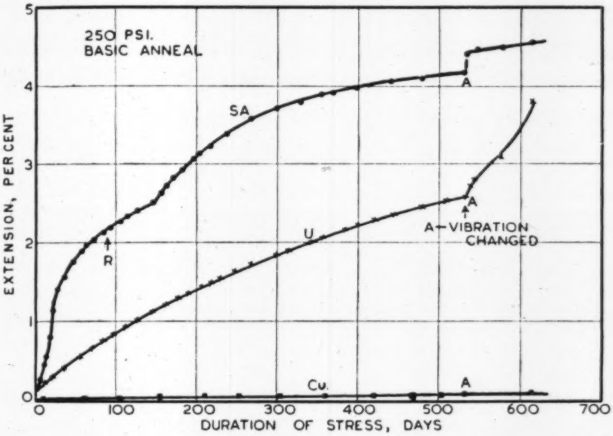


FIG. 14.—Total Strain Time Curves, Stress 250 psi., Strip Basic Annealed.
R means that recrystallization was noted at this point.

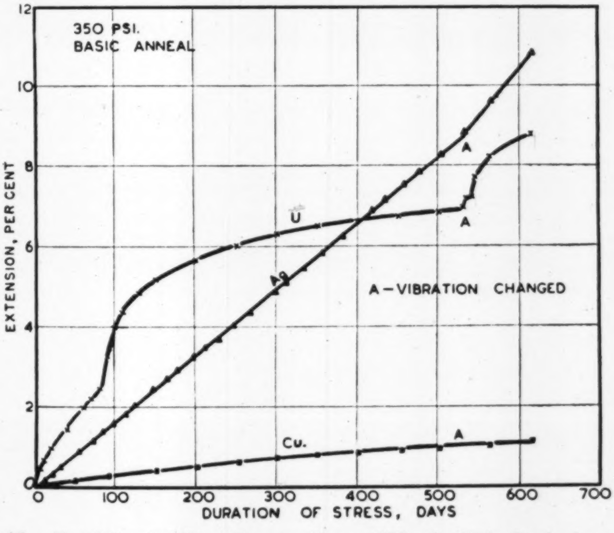


FIG. 15.—Total Strain-Time Curves, Stress 350 psi., Strip Basic Annealed.

Although there are not sufficient points to determine the creep yield stress with any accuracy under these conditions, there is an indication in Fig. 16 that the value is about 160 psi. (1 per cent extension in 1 yr.). Under conditions free from vibration, the corresponding value is over 250 psi. as can be seen from Table III.

Influence of Stress on U lead:

This was an ordinary high grade industrial lead but not quite so pure as SA. The results for this lead under vibratory conditions are shown in Fig. 8 (basic anneal) and in Fig. 9 (stabilizing anneal). Comparative results are given in Tables V and VI.

As in the case of the very pure lead (SA), vibration caused an appreciable increase in the rate of creep. Below the creep yield stress for static conditions (300 psi.), this increase is fourfold to sixfold. In the higher ranges of stress, this factor becomes confused by the recrystallization phenomenon.

Observation on this lead also confirms the fact that vibration facilitates recrystallization. In Table IV it is shown that without vibration 4 to 5 per cent elongation is necessary to cause recrystallization in the basic annealed condition while with vibration about 2.5 per cent was sufficient. It is interesting to note, too, that both these values are somewhat higher than the corresponding values for the purer lead (SA).

The influence of the stabilizing anneal is shown by comparison between Figs. 8 and 9 and in Table VI. The values in the last column are approximately one third those for the basic annealed condition. It will be noted, from Fig. 9, that this lead extended 3.5 per cent without recrystallization, while in the basic annealed condition 2.5 per cent was sufficient.

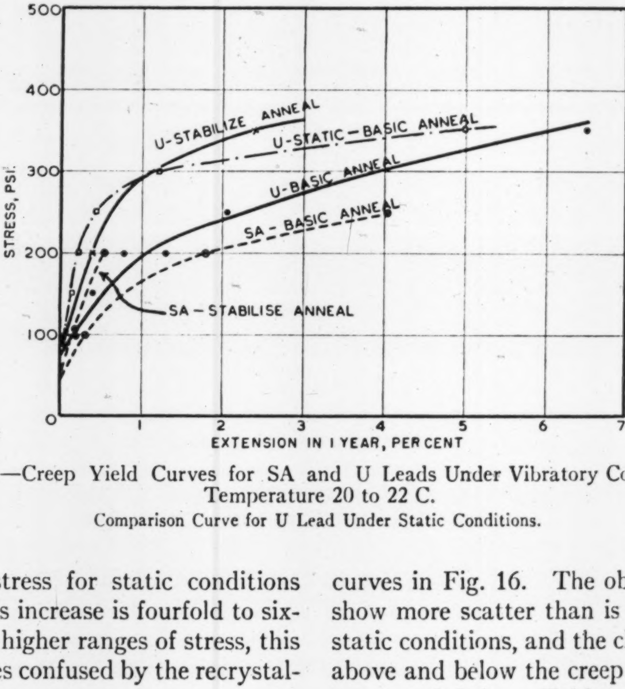


FIG. 16.—Creep Yield Curves for SA and U Leads Under Vibratory Conditions, Temperature 20 to 22 C.
Comparison Curve for U Lead Under Static Conditions.

The creep yield stress is lowered by vibration. This can be seen from the curves in Fig. 16. The observed values show more scatter than is the case with static conditions, and the change in slope above and below the creep yield stress is not so definite. Taking however the criterion previously used, namely, 1 per cent extension in 1 yr., it is found that the creep yield stress under vibratory conditions is 200 psi. as compared with 290 psi. without vibration. In Fig. 16, the corresponding curve for static conditions is also shown for comparison.

Influence of Stress on Silver Lead:

As previously mentioned, this alloy was made by adding 0.027 per cent silver to the U lead. One of the results of this addition was that the grain size in the finished condition was appreciably smaller than that of the basis lead. The relative values are given in Table I. It should also be remembered that as the solid solubility of silver in lead at ordinary temperatures is of the order of 0.01 per cent, part of the silver in this alloy was dispersed as fine particles.

The results are plotted in Fig. 10 and some comparative figures are given in Table VII.

From these figures it is seen that although again vibration increases the creep rate, the effect is not so great as with the pure leads. At the lower stress the rate under vibration is about twofold, while at the higher stress it is of the same order as the rate under static conditions.

TABLE VIII.—INFLUENCE OF 0.027 PER CENT SILVER ON CREEP RATE OF LEAD UNDER VIBRATORY CONDITIONS.

Stress, psi.	Elongation After 1 yr., per cent			
	U lead		0.027 per cent Ag lead	
	100 C. for 15 min.	125 C. for 24 hr.	100 C. for 15 min.	125 C. for 24 hr
100	0.2	0.08	0.2[a]	....
200	1 3	0.4	1.08	1.24
250	2.2	....		....
350	6.5[b]	2.45	5.9[b]	7.8

[a] Extrapolated from 120 days.
[b] To see how misleading such figures can be, compare the corresponding curves in Fig. 15.

Although elongations of the order of 15 per cent were reached, there was never any evidence of recrystallization in this alloy. Another interesting feature, probably associated with the last, is that the curves do not exhibit that falling creep rate with extension which is characteristic of the pure leads.

In Table VIII two comparative sets of figures are shown.

The creep rate after the two annealings is shown and also the corresponding figures for the basis U lead. It will be seen: (*a*) that contrary to the effect with pure lead, the stabilizing treatment causes a slight increase in creep rate, and (*b*) consequently, although in the basic annealed condition there is little difference between the rates for the pure lead and the alloy, respectively, in the stabilized condition, the alloy creeps at about three times the rate of the basis lead.

As was mentioned earlier, a homogenizing anneal was also given to this alloy during the rolling procedure. The final treatment of the strip, however, was the basic anneal. The effect of this billet anneal was probably a redistribution of some of the silver. From Fig. 10 and Table IX it is seen that an appreciable increase in creep rate occurred as a result of this treatment. This is not so marked at 100 psi. as at 200 and 350 psi.

TABLE IX.—INFLUENCE OF HOMOGENIZING (BILLET) ANNEAL ON CREEP RATE OF 0.027 PER CENT SILVER LEAD UNDER VIBRATORY CONDITIONS.

Stress, psi.	Elongation After 1 yr., per cent	
	Rolled Direct	Billet Anneal
100	0.2	0.3
200	1.1	3.3
350	6.0	18[a]

[a] Extrapolated from 120 days.

Influence of Stress on Copper Lead:

As in the case of the addition of silver, the addition of 0.075 per cent copper to lead caused an appreciable reduction in grain size as recorded in Table I. The solid solubility of copper in lead is very low (0.005 per cent at 290 C.). The added copper is therefore almost entirely dispersed as such, since lead and copper do not form any intermediate phase. Under conditions of laboratory preparation, this copper will be more finely dispersed than in industrial material, the larger masses of which would cool much more slowly, except perhaps in the case of extrusion of cable sheathing. Hence the introduction of the billet anneal in an endeavor to obtain a coarser dispersion of the copper by coalescence.

The results for this alloy are shown in Fig. 11 and some comparative values are given in Table X.

The only comparable value available in the static condition is from a test carried out on an alloy containing 0.066 per cent copper under stress of 350 psi. From this, it will be noted that here again there is an appreciable increase in the creep rate under vibratory conditions.

TABLE X.—COMPARISON OF CREEP RATES OF 0.07 PER CENT COPPER LEAD WITHOUT AND WITH VIBRATION.
(Annealed 100 C. for 15 min.).

Stress, psi.	Elongation, per cent			
	Without Vibration		With Vibration	
	After 1 yr.	After 2 yr.	After 1 yr.	After 2 yr.
350	0.12	0.26	0.8	1.3

TABLE XI.—INFLUENCE OF 0.07 PER CENT COPPER ON THE CREEP RATE OF LEAD UNDER VIBRATORY CONDITIONS.

Stress, psi.	Elongation after 1 yr., per cent			
	U lead		0.07 per cent Cu Lead	
	100 C. for 15 min.	125 C. for 24 hr.	100 C. for 15 min.	125 C. for 24 hr.
200......	1.3	0.4	less than 0.05	0.12
250.....	2.1	....	0.05	....
350.....	6.5^a	2.45	0.8	0.8

[a] Recrystallized during test.

In Table XI comparative values are given for the copper lead and for the basis U lead in two annealed conditions.

From these tables it is seen: (*a*) that the values for the two annealings are very similar, and (*b*) the creep rate is much lower than for the basis lead in both conditions.

Finally, the influence of redistributing the copper is shown in Fig. 11 and in Table XII.

The effect of this treatment was to coalesce the particles of copper, giving a coarser distribution. It will be seen that there was a marked effect on the creep rate. If comparison is made between the results on the coalesced specimens in Table XII with those for U lead under the same conditions given in Table V it will be seen that the rates of creep are very similar. In other words all advantage from the addition of copper has been lost. It should, however, be noted that no indication of recrystallization was observed in this alloy even though in one test it stretched 16 per cent in two years.

TABLE XII.—INFLUENCE OF BILLET ANNEAL ON CREEP RATE OF 0.07 PER CENT COPPER ALLOY UNDER VIBRATORY CONDITIONS.

Stress, psi.	Elongation After 1 yr., per cent	
	Rolled Direct	Billet Anneal
100.......	....	0.19
200.......	less than 0.05	0.8
350.......	0.8	6.6

Influence of Composition at a Stress of 100 psi.

These results are grouped in Fig. 12. The treatment of the test specimens in each case was the basic anneal, but in the case of the silver lead, as the test was conducted for 120 days only, another curve for a test specimen prepared from material which was subjected during production of the strip to the "billet anneal" is also given. It is noted that the latter curve is substantially a continuation of the former.

At this stress the order of magnitude of creep rate for the two pure leads and for the silver lead is substantially similar, though it would appear that after 2 yr. the silver lead would continue to extend at a greater rate than the two pure leads.

The copper lead (with copper highly

dispersed) showed a zero creep rate for 120 days.

Influence of Composition at a Stress of 200 psi.:

The results are grouped in Fig. 13.

In this case, also, the two pure leads and the silver lead creep at about the came rate, but the copper lead at a much slower rate.

In this case a comparison was also made of U lead with two different grain sizes. The test specimen with larger grain size (3 to 4 mm.) showed a greater initial stretch but a much lower creep rate than the one with smaller grain size (0.5 mm.).

Influence of Composition at a Stress of 250 psi.:

These results are grouped in Fig. 14.

Under this stress, giving rise to greater rates of extension, the phenomenon of recrystallization under stress became evident. The SA lead recrystallized very early in the test and again after 2.5 per cent extension whilst the U lead recrystallized first after 2.5 per cent. Again the highly dispersed copper lead shows a very much lower creep rate.

Influence of Composition at a Stress of 350 psi.:

The results are grouped in Fig. 15.

The U lead recrystallized after 2.3 per cent extension and again after 6.8 per cent. The silver lead showed an approximately constant creep rate with characteristics quite different from those of the basis lead from which it was made. Again the copper lead had a much lower creep rate.

CONCLUSIONS

From the foregoing results, the following conclusions can be drawn:

1. The creep rate of lead is appreciably increased by vibration.

2. The recrystallization of lead under stress is accelerated by vibration, that is, it occurs with lower percentage extension. This point is further illustrated by the two curves for U lead under 200 and 250 psi. (Fig. 8). These test specimens were examined and the original grain size confirmed after 2.3 and 2.7 per cent extension, respectively. Immediately after this examination, deviations usually associated with recrystallization occurred in both curves. After the vibrator was finally stopped, the specimens remained under stress for 8½ yr. (10) during which time the stress time relationship was linear. On examining these specimens after 11 yr. from commencement of test, it was found that approximately half the gage length in each case had recrystallized (Fig. 6). It is evident, therefore, that although recrystallization had actually started during the vibration period and had made considerable progress during a period of 70 days, it either ceased or made only slow progress during the succeeding 8½ yr. under the same stress but without vibration.

3. The creep yield stress (giving 1 per cent extension in 1 yr. is appreciably reduced by vibration (Fig. 16). In the basic annealed condition the creep yield stress for U lead is 290 psi. for a static load and 200 psi. with vibration.

4. The structure of lead can be "stabilized" by annealing 24 hr. at 125 C. In this condition the creep rate is appreciably lower than in the basic annealed (100 C. for 15 min.) condition, the recrystallization under stress with or without vibration does not occur, and the creep yield stress is increased, being the same *with* vibration in the "stabilized" condition as *without* vibration in the basic annealed condition (Fig. 16).

5. The influence of the addition of 0.027 per cent silver is as follows:

(*a*) The type of relationship between strain and time is changed, the silver alloy showing no tendency to decreasing creep rate with time.

(*b*) The alloy does not recrystallize under stress or vibration up to extensions of the order of 15 per cent.

(*c*) The creep rate of the silver alloy is accelerated by vibration in much the same way as with pure lead.

(*d*) Annealing at 250 C. during the working operations (billet anneal) yields strip which has a greater creep rate for a given stress than either the basic annealed alloy or the basis lead from which it was made. These differences in creep rate are more marked as the applied stress is increased.

6. The influence of the addition of 0.07 per cent copper is as follows:

(*a*) The creep rate of the strip rolled direct from the ingot (and finally basic annealed) is much lower than for the corresponding basis lead.

(*b*) If, however, an intermediate anneal at 250 C. is carried out during rolling operations the creep rate becomes similar to that of the basis lead. In this condition, however, it shows none of the tendency to recrystallize possessed by the basis lead (up to 15 per cent extension).

(*c*) The change in creep rate caused by the intermediate (billet) anneal is considered to be associated with the coalescence of the copper particles which takes place. If this is so, then the great improvement in creep resistance due to addition of 0.07 per cent copper found in laboratory experiments might not be obtained with the more slowly cooled masses used in industry. On the other hand, it might be representative of the behavior of extruded alloy sheathing which would cool relatively quickly.

REFERENCES

(1) J. Neill Greenwood, "Effect of Heat Treatment on the Mechanical Properties of Commercial Lead," *Proceedings*, Australasian Inst. Mining and Metallurgy, (NS) Vol. 95 (1934).

(2) R. S. Russell, "Creep Tests on Electrolytic Lead and Some of Its Alloys," *Ibid*, (NS) Vol. 101, (1936).

(3) J. Neill Greenwood and Howard K. Worner, "Influence of Tellurium on the Creep Rate of Commercial Lead," *Ibid*, (NS) Vol. 101 (1936).

(4) J. Neill Greenwood and Howard K. Worner, "Influence of Composition (Ag, Sb, Bi, Zn) on Creep Rate of Industrial Lead," *Ibid*, (NS) Vol. 104 (1936).

(5) J. Neill Greenwood and C. W. Orr, "Influence of Copper on Creep Rate of Lead," *Ibid*, (NS) Vol. 109 (1938).

(6) J. Neill Greenwood and C. W. Orr, "Influence of Calcium on Creep Rate of Lead," *Ibid*, (NS) Vol. 112 (1938).

(7) J. Neill Greenwood and C. W. Orr, "Influence of Magnesium on Creep Rate of Lead," *Ibid*, (NS) Vol. 113 (1939).

(8) J. Neill Greenwood and Howard K. Worner, "Types of Creep Curve Obtained With Lead and Its Dilute Alloys," *Journal* Inst. Metals, Vol. LXIV, p. 35 (1939).

(9) J. Neill Greenwood and J. H. Cole, "Creep Rate of Various Industrial Leads," *Metallurgia*, Vol. 36, p. 233 (1947).

(10) J. Neill Greenwood and J. H. Cole, "Influence of Various Factors on the Creep of Lead," *Ibid*, Vol. 37, No. 222 (1948).

(11) J. Neill Greenwood and J. H. Cole, "Influence of Various Factors on the Creep of Lead Alloys," *Ibid*, Vol. 37 (1948).

(12) J. Neill Greenwood and J. H. Cole, "Influence of Calcium on the Creep Characteristics of Lead," *Ibid*, Vol. 39, (1949).

(13) Curtis W. Dollins, "Investigation of Creep Fracture and Bending of Lead and Lead Alloys for Cable Sheathing." *Bulletin*, University of Illinois, Engineering Experiment Station, Vol. 45, No. 65 (1948).

DISCUSSION

MR. G. R. GOHN[1] (*presented in written form*).—Mr. Greenwood and his associates at the University of Melbourne have contributed a great deal to our knowledge of the behavior of lead under continuously applied loads (creep). Unfortunately, the results of most of their studies have appeared in publications which have not been too readily available in this country; hence their findings are, perhaps, not as familiar to engineers concerned with the high-temperature applications of metals and alloys as they are to the manufacturers and users of cable sheathing and industrial lead or lead alloy sheet. Therefore, it is gratifying to have one of Mr. Greenwood's papers on the creep of lead presented before an American technical society where it will come to the attention of this larger group.

The author's present paper on the influence of vibration on creep is one of considerable interest today because the development of the gas turbine and the jet propulsion engine, as well as certain aircraft developments, has created a demand for engineering data on the behavior of materials under various combinations of stress. This demand has been particularly great in the case of metals and alloys subjected to fatigue stresses while operated at elevated temperatures of such magnitude that plastic deformation or creep becomes an important factor. Now lead and lead alloys at room temperature behave in many respects like other metals at elevated temperatures, and observations made from tests on lead alloys subjected to both vibration and creep should be helpful to those interested in the high-temperature field.

Cable engineers, both in the communication and in the power field, have long known that superimposed vibratory or fatigue stresses would have a deleterious effect upon the creep characteristics of extruded lead cable sheath. Unfortunately, however, quantitative data have been lacking as to the magnitude of this effect. Apparently this problem is also of concern to those whose primary interest lies in the mechanism of creep and in the use of rolled lead sheet. As a result of that interest we now have offered to us by Mr. Greenwood some quantitative confirmation that fatigue stresses superimposed upon lead or lead alloy specimens subjected to continuously applied steady loads will adversely affect the creep characteristics.

In considering the data presented by the author, it would be very helpful if he would furnish further details on the rolling schedules used in preparing the various sheet materials since it is known that the creep characteristics of lead and lead alloys depend, to a large extent, upon their prior history. The significance of this dependency should not be overlooked by the reader in considering the application of Mr. Greenwood's findings. As a further aid to those who are interested in confirming or extending the work of the author, it would be helpful if he would indicate the strain amplitude and maximum instantaneous acceleration corresponding to the added vibratory stress.

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If this information is not available from the present tests, it could readily be obtained in any future work by feeding the output of a wire strain gage mounted on the creep specimen into an oscilloscope and recording the instantaneous values of strain at any time in the stress cycle.

A study of the paper indicates that all of the samples were given an annealing treatment prior to test. This treatment, in most cases, produces a stable metallurgical structure but one which is different from that obtained in commercially rolled sheet lead which is normally finished by cold rolling and far different from that normally found in extruded cable sheath or pipe. Since it appears that the author's test specimens have a metallurgical history intended to produce a stabilized structure rather than to simulate service conditions, I believe that, pending a more complete study of the effect of combined stresses on the creep characteristics of material finished either by cold rolling to simulate sheet applications or by extrusion to simulate cable applications, we should consider that the author's findings have more of a theoretical rather than a practical application.

The author shows that in the form of cold-rolled and annealed sheet, an addition of 0.027 per cent of silver to pure lead results in an alloy having a greater rate of creep than either of the high-purity leads (SA or U). He therefore concludes that silver has no beneficial effect upon the creep characteristics other than to suppress the recrystallization that occurs in pure lead under stress when the strain reaches 4 to 5 per cent. On the other hand, Phelps, Kahn, and Magee[2] and Gohn and Ellis[3] found, from studies made on extruded pipe samples tested "as extruded" with no more cold working than that equivalent to unreeling, that, at stresses of 250 psi. and above, silver in amounts up to at least 0.010 per cent were beneficial and tended to reduce the creep rate. All of the materials with 0.010 per cent of silver or less tested by the latter[2,3] had an average grain size comparable to that of Mr. Greenwood's silver-bearing alloy, whereas his alloy had about $\frac{1}{3}$ to $\frac{1}{2}$ the grain size of the high-purity lead alloys which he tested. Now McKeown[4] has shown that within the range of grain sizes normally found in extruded sheath, the creep rate of lead and its alloys decreases with increasing grain size. This has also been confirmed by some unpublished work carried out in our own laboratories on extruded lead-calcium pipe. What evidence does the author have that the observed differences between the creep rate of the silver-bearing lead and the two high-purity leads are not due to grain size variations or other variations in the method of preparing the samples rather than due primarily to the presence or absence of silver?

The author's observations that the presence of copper in a dispersed form is beneficial whereas agglomeration of the copper by annealing results in a material having a creep rate comparable to that of the basis metal are interesting and are in agreement with the findings of Gohn, Arnold, and Bouton[5] on antimonial lead. It would be of considerable interest if the author would show photomicrographs of the different types of structure for the copper-bearing lead resulting from heat treatment.

The author's introduction of the term "creep-yield stress"—which he defines on page 835 as the knee of the creep-yield curve (or preferably of the stress-extension curve)—is novel and may prove to be a very useful concept from a theoretical standpoint, provided it can be established that the mechanism of creep is different above and below this point. This difference in the mechanism of creep at high and low stresses is suggested by the author when he states that below the creep-yield stress, creep affects chiefly the boundary zone of the crystal while above this stress, creep affects the body of the crystal as well. We have pointed out in a previous paper[3] that the mechanism of creep is different at high stresses from what it is at low stresses but as yet we have no clear-cut evidence to support this thesis. In view of Mr. Greenwood's statement, we wonder if he is able at this time to offer microscopic or other evidence to substantiate this statement.

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[2] H. S. Phelps, F. Kahn, and W. P. Magee, "Influence of Small Percentages of Silver on the Tensile Strength of Extruded Lead Sheathing," *Proceedings*, Am. Soc. Testing Mats., Vol. 48, p. 815 (1948).

[3] G. R. Gohn and W. C. Ellis, "The Effect of Small Percentages of Silver and Copper On the Creep Characteristics of Lead," *Proceedings*, Am. Soc. Testing Mats., Vol. 48, p. 801 (1948).

[4] John McKeown, Discussion on Worner paper, *Journal*, Inst. Metals, Vol. LXIV, No. 1, p. 160 (1939).

[5] G. R. Gohn, S. M. Arnold, and G. M. Bouton, "Creep Tests on Some Extruded Lead and Lead-Alloy Sleeves and Tapes," *Proceedings*, Am. Soc. Testing Mats., Vol. 46, p. 990 (1946).

In analyzing the data in the present paper the author defines the creep-yield stress not as the "knee in the curve" referred to on page 835 but as the stress required to produce 1 per cent extension in 1 year. This value the author considers to be of significant value in connection with design (see page 835). With this we are forced to disagree.

Reference to Fig. 1 and to Fig. 15 shows that in some cases 1 per cent elongation per year corresponds to the stress at which the knee in the stress-extension curve occurs, but in other cases the knee occurs at values of extension other than 1 per cent, and in some cases no knee is observed. From a practical standpoint, 1 per cent elongation per year is a higher rate of creep than can be tolerated in practice. For example, cable designs are predicated upon an elongation of the order of 1 per cent in 10 yr.

MR. J. NEILL GREENWOOD (*author*).—Mr. Gohn's introductory remarks are timely. In all our work on creep using lead as a basic material we have held the view that the experiments could serve the dual purpose of defining the influence of elements on the behavior of lead under stress on the one hand and the more general topic of the behavior of metals under stress at high temperature on the other hand. The phenomenon of slow deformation under stress has proved to be so complex that it was our opinion that initial cold work should be eliminated. Regarding the preparation of the test specimens used, there is nothing further to add except that this was entirely in the laboratory and that the material was rolled by light passes of a few thousandths of an inch only from 1 in. thickness to $\frac{1}{8}$ in. The strain amplitude caused by vibration is not known.

Regarding the influence of silver, it has been shown (reference **4** of this paper) that *under static conditions* this element does reduce the creep rate appreciably, and a maximum effect was noted at about 0.03 per cent. For this reason the alloy containing 0.027 per cent used in the present tests was chosen. The statement now referred to by Mr. Gohn is qualified by inclusion of the words "under vibratory conditions." The work of McKeown referred to was not carried out under sufficiently critical conditions in his (the author's) opinion to establish anything relating to the influence of grain size on creep rate. The comparison was not even made on one batch of lead, and the extrusion was done under industrial conditions. It so happens that, as in Mr. Gohn's laboratory so in the author's laboratory evidence has been obtained that the conclusion reached by McKeown is, however, correct. The answer to Mr. Gohn's query is, that in working with many series of alloys, grain sizes comparable with that developed by silver have been obtained. Sometimes the creep rate is appreciably less than that of pure lead, sometimes appreciably greater. The assumption seems justified that the changes are due to the solutes present.

The micrographs relating to the degree of dispersion of copper in the alloy used are given in reference **5** of this paper.

Evidence relating to the difference in mechanism of creep at low and high rate of deformation is difficult to obtain because of the very small effects and the long time required to obtain observable results under very low stresses. It has however been shown by Wilms and Wood[6] in our laboratory that for high rates of creep the mechanism is either by slip or by fragmentation to sub-grains which differ in orientation from one another by about 1 deg. These sub-grains appear to be able to more relative to one another. We consider (in the absence of direct evidence) that at low stresses only the *crystal boundaries* make an effective contribution to creep but at higher rate of strain more and more *crystals* begin to contribute to the deformation by one or other of the mechanisms mentioned.

Mr. Gohn will appreciate that in discussing creep results there are so many interlocking factors that it is impossible to make any *simple* statement which will pass without criticism. So, in the present case, the *idea* of "creep-yield" was introduced, without the possibility of precise definition at this stage. The tentative use of 1 per cent extension in 1 yr. was merely to give some comparative value by which to judge the results. In a polycrystalline mass, the number of crystal boundaries or crystals contributing to the deformation at any stage is such a complex function of strain rate, grain size, temperature, and intrinsic properties both of boundary and crystal that no precision is possible in defining "creep-yield."

The author appreciates the careful study which Mr. Gohn has made of this paper and would point out the close correlation which has been shown to exist between the more practical tests carried out in America and these experiments in Melbourne, which has been referred to in the author's recent publications (references **9, 10, 11, 12** of this paper). In the present state of our knowledge small differences must be ignored, and if there is broad general agreement we must be satisfied. The detail will need to await further experiment.

MR. H. F. MOORE.[7]—In tests of lead specimens cut from cable sheathing we have found at the University of Illinois that vibration shortens the life of such specimens. The vibratory loads applied ranged from 10 to 20 per cent of the steady load.

Since the Illinois tests were made on specimens cut from pieces of cable sheathing, the effects of the extrusion of the cable probably changed somewhat the results of the creep-to-fracture tests, both of the tests with vibration and those without.

MR. M. J. MANJOINE.[8]—In connection with the presentation of my paper, Mr. Moore and I discussed the case of adding an alternating stress to the steady stress in a creep test of lead.[9] The creep rate for lead shows an increase while that for many other alloys may show a decrease. If the average creep rate for a test under steady load is compared with that for one with a superimposed alternating stress of very low frequency, then the latter test will show a higher average rate because of the much greater rate of strain at the higher stresses. If, however, the frequency of the alternating stress is increased so that a higher rate of application of the load will occur, then the material appears to be stronger. This increase in strength is a result of a different mechanism of flow than that occurring in a creep test. It is this mechanism of flow which we must check upon to get the difference between the flow of lead and that of some of the other alloys.

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[6] G. R. Wilms and W. A. Wood, "Mechanism of Creep in Metals," *Journal*, Inst. Metals, Vol. LXXV, p. 693 (1949).

[7] Research Professor of Engineering Materials, Emeritus, University of Illinois, Urbana, Ill.

[8] Research Engineer, Mechanics Dept., Westinghouse Research Labs., Westinghouse Electric Corp., East Pittsburgh, Pa.

[9] Joint discussion of B. J. Lazan's paper, "Dynamic Creep and Rupture Properties of Temperature-Resistant Materials Under Tensile Fatigue Stress," and M. J. Manjoine's paper, "Effect of Pulsating Loads on the Creep Characteristics of Aluminum Alloy 14S-T," see p. 799 of this publication.

MR. P. E. CAVANAGH.[10]—I have two simple questions. I think Mr. Manjoine has just answered one of them.

First, is there any fundamental difference expected in the results obtained by introducing the same small amounts of additional energy to the creep process by vibration or by raising the temperature?

And, secondly, where there is a conflict in results as we have heard discussed several times is it possible that part or most of the vibration energy is not contributing to the creep process but is being dissipated in other ways?

MR. GOHN.—The small amount of vibration superimposed upon the creep stress by Mr. Greenwood caused a shift of the extension-time curve of approximately one decade along the time axis. Some work which Phelps, Kahn, and Magee[2] did, in which the temperature of test was increased from 85 to 110 F., caused a similar shift in the extension-time curve. Now, whether it can be said that the effects of adding small amounts of energy by vibration or by thermal agitation are equivalent or not, I don't know, but the displacement of the extension-time curve was of the same order in both cases.

MR. R. E. PETERSON.[11]—This particular question is not discussed in the present paper, but perhaps Mr. Greenwood has some information bearing on the question.

In Mr. Lazan's paper,[12] he showed that under certain special conditions the creep-rupture life was increased by a small amount of vibration. Mr. Lazan's[12] tests were made with steel at high temperature, and I am wondering if Mr. Greenwood has found a similar result with lead alloys at room temperature.

MR. GOHN.—I am afraid that I am not able to answer Mr. Peterson's question, in the author's absence, because in the case of creep tests on lead alloys, the effect which he has described is masked by something which occurs as a result of aging while the specimen is under continuous load. In such tests we find that the elongation which is measured across the broken ends of the specimen after failure in the stress rupture test at high stresses is relatively large, but that as the stress decreases and the time to failure increases, a metallurgical change takes place in the lead alloy and the elongation after failure decreases markedly. This loss in elongation is not observed in shelf-aged specimens broken in a short-time tension test. All of our own vibration tests were made at lower stress levels so that the loss in elongation may have been masked by the normal decrease in elongation which has been attributed to aging. Perhaps this should not be attributed to aging alone but it is definitely a function of time and stress.

J. NEIL GREENWOOD (*author's closure*).—In closing I should like to thank Mr. H. F. Moore for his courtesy in introducing my paper. I also thank all those who took part in the discussion.

I was interested in the point made by several contributors, that materials may appear stronger at high frequencies of vibratory stress. It appears to me that an alternating stress might influence the rate of creep in two ways: (*a*) by subjecting the metal to short-time applications of a peak load higher than the mean and (*b*) by imposing additional elastic stress across boundary surfaces—whether these be crystal boundaries or crystallographic planes. In the case of (*a*) evidence from the influence of single shocks does not lead one necessarily to expect an increase of creep rate. In the case of (*b*) the effect would be to increase the tendency to intercrystalline or intracrystalline cracking. I have never noticed any increase of life due to vibration, but in the experiments reported, no systematic variation of the effect of frequency of vibration was made.

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[10] Assistant Director, Dept. of Engineering and Metallurgy, Ontario Research Foundation, Toronto, Ontario, Canada.

[11] Manager, Mechanics Dept., Westinghouse Research Laboratories, Westinghouse Electric Corp., East Pittsburgh, Pa.

[12] B. J. Lazan, "Dynamic Creep and Rupture Properties of Temperature-Resistant Materials Under Tensile Fatigue Stress," see p. 757 of this publication.

Mr. Gohn mentioned an aging effect in lead alloys which results in a decrease of total elongation after fracture, as stress is decreased and life to rupture increased. This same feature is found also with pure lead, and is not related to an aging phenomenon but to the greater relative importance of grain boundaries at lower stresses. The decreased elongation in such cases is accompanied by a greater tendency to intercrystalline cracking.

MAGNETISM IN COPPER ALLOYS: THE EFFECT OF IRON AS IMPURITY*

By Allison Butts[1] and Paul L. Reiber, Jr.[2]

Synopsis

The magnetic susceptibilities and residual magnetic moments of 19 copper alloys containing varying percentages of iron as impurity were measured under different conditions of thermal and mechanical treatment. Graphs were plotted of the magnetic properties against iron content. Data were obtained on which specifications may be based for maximum iron content in alloys for the construction of instruments in which only weakly magnetic materials are permissible.

Three of the alloys were found to be unsuitable for use in such instruments under any conditions. The remaining sixteen alloys would be suitable if the iron content were as low as 0.01 per cent, and some may contain higher percentages of iron. A solution-quenching treatment was found to be effective in lowering the magnetic properties of most of the alloys. The relative suitability of the alloys as regards rate of increase in magnetism with increasing iron content was determined. Among the cast alloys, without heat treatment, three common brasses and bronzes were rated as good, two fair, and four poor in the sense that their magnetic properties began to rise rapidly at iron contents below 0.10 per cent.

Binary aluminum bronze was found to be the best wrought alloy at low iron contents and 18 per cent nickel silver was best at higher iron contents. No other wrought alloys were rated good unless heat treated, but four wrought alloys and six cast alloys were rated either "best" or "good" after heat treatment.

A general pattern or type of curve for increase in magnetism with iron content was found.

Annealing caused rises in the magnetic properties which were inappreciable at very low iron contents but increased rapidly with percentage of iron.

Information bearing on the practical significance of the magnetic data was obtained by correlating the deflections of the compass needle of a surveying instrument with known susceptibilities and magnetic moments. Magnetism produced by small amounts of unalloyed iron was measured and compared with that caused by the same amount of iron alloyed in the specimens.

The correlation of magnetic properties with alloy composition is discussed briefly.

Instruments containing compass needles or other magnetic devices may be subject to error because of small amounts of magnetism in housing, frames, and nearby parts made of material ordinarily regarded as nonmagnetic. Specifications for the copper alloys commonly used in instrument construction are based on considerations of manufacture and structural service; they permit maximum contents of iron as impurity so high in many cases as to render the material unfit for use in magnetic instruments, even when the actual iron content is much less than the stated allowable maximum. If the alloys are made of high-grade primary metals with due care to avoid contamination in manufacture, suitably low iron contents and hence suitably low magnetic properties may be obtained; but if secondary metals are used or contamination occurs, serious deficiencies in instrument functioning may be encountered.

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* Presented at a meeting of Committee B-5 on Copper and Copper Alloys, Cast and Wrought, held on March 10, 1949 in Washington, D. C.

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This matter was brought to the attention of the Laboratory Division (now the Pitman-Dunn laboratory) of the Frankford Arsenal during the recent World War, and under the initiative of Lt. Col. C. H. Greenall, officer in charge of the Laboratory Division, a project for the investigation of the effect of impurities on magnetism in non-ferrous alloys was instituted and an O.S.R.D. contract for the work was entered into between the United States Army Ordnance Department and Lehigh University (N.D.R.C. Research Project N.R.C.-79, O.D.-156). After N.D.R.C. became inactive the investigation was continued under a second United States Army Ordnance contract (Project 1/24). Initially, the work was directed toward measurements of the magnetic properties of various copper alloys used in instrument construction, with particular reference to the effect of iron as impurity and looking toward consideration of the desirability of establishing specifications for alloys to be used in the structural parts of magnetic instruments. Information and inquiries received from various sources indicated that magnetism in instrument parts is a frequent source of inaccuracy and uncertainty, not only in military, naval, and aircraft equipment in war, but also in scientific and control instruments in time of peace.

The complete investigation embraced a study not only of the effects of iron as impurity in copper alloys, but also the broader aspects of variation of magnetic properties with composition, and the effects of such metallurgical factors as mechanical work, heat treatment, aging, and variation in casting conditions. It is not the purpose of the present paper to cover the entire investigation, but to compare the copper alloys studied (19 in number) as regards magnetic properties, to rate them as to suitability for use in magnetic instruments with particular reference to increase in magnetism with increased contents of iron impurity, and to present the data obtained as bearing on possible specifications for maximum iron content when the alloy in question is to be used in magnetic instruments.

MAGNETIC PROPERTIES MEASURED

The ability of a diamagnetic or a paramagnetic substance to become magnetized is measured by its magnetic susceptibility, which was accordingly chosen as one of the properties to be measured. Susceptibility may be defined either on a volume or on a mass basis, but in this work the mass susceptibility, χ, is reported exclusively. This is defined by the magnetic moment per gram, σ, while in the magnetizing field divided by the field strength, H:

$$\chi = \sigma/H \qquad (1)$$

The specimens used for measurement in the investigation were solid disks of approximately uniform dimensions having a volume of 1.3 cu. cm. The mass of the specimen was between 9 and 10 g., varying with the density of the alloy.

The magnetizing force in service may be the magnetic field of a compass needle or other small magnet contained in an instrument, together with the Earth's magnetic field, or it may result from accidental exposure to a magnetic field of perhaps considerably greater magnitude.

The force which the magnetized part may exert is equally important. This force is a function of the magnetic moment, *M*, which was chosen as the other property to be measured. The value of *M* falls off after magnetization, the rate of decline differing with different substances. The magnetic moment per unit volume after *H* has been removed or reduced to zero is termed the residual magnetization, or sometimes remanent magnetic moment per cubic centimeter. The "magnetic moment" reported in this paper is that obtained directly by the measurements, using the specimen of volume 1.3 cu.cm., after magnetizing in a nearly constant field of 436 gauss and measured usually one day after removal from the field. Under these conditions the same specimen could be used first for measurement of susceptibility on one day and then for measurement of magnetic moment on the following day; 436 gauss was the field strength of the solenoid in which the susceptibility was measured, so that no additional magnetization was required.

The measurements of magnetic moment may be said to be comparable for all the alloys in that the field strength was fixed and the elapsed time nearly so. It cannot be stated with certainty that a different field strength would affect all the alloys in the same degree, but measurements of susceptibility of copper in which varying small amounts of iron had been dissolved gave values agreeing closely with those obtained by Bitter and Kaufmann **(2)**,[3] although the latter used a much higher magnetizing field. It is probable that the low susceptibilities of the copper-base alloys with which this investigation was concerned are nearly independent of field strength when the latter is as high as 436 gauss.

The rate of decrease in residual magnetic moment in 70-30 brass containing iron impurity has been measured by C. S. Smith **(9)**. His graph of magnetic moment plotted against time showed that a considerable drop occurred in the first hour, followed by a lesser rate of fall in the next 5 hr. and only a very gradual fall thereafter up to 27 days, the period of the test. In the present study, remanent magnetic moments were determined on three series of specimens one day after and again 19 days after magnetization. No significant decrease was found in this time. Since the elapsed time after removal from the magnetic field in this work was usually one day, and never less than one or more than four days, it is believed that the reported values for magnetic moments of the different alloys are on a comparable basis. There may well be a considerable drop in a period of several weeks or months; the reported values for magnetic moment accordingly represent the maximum values that would be encountered in service several hours after removal from a magnetic field. The reported susceptibilities permit calculation of magnetic moment while in a field of known strength.

The suceptibilities are given in the units which have been widely adopted for measurements of this order, namely, c.g.s. units times 10^{-6}. The magnetic moments are stated in c.g.s. units times 10^{-3}.

METHODS OF MAGNETIC MEASUREMENT

For measurement of residual magnetic moment there was employed an electrodynamic method using an apparatus designed by E. A. Johnson and A. G. McNish and constructed at the Department of Terrestrial Magnetism, Carnegie Institution of Washington. The apparatus was kindly loaned to Lehigh University by the Carnegie Institution through the courtesy of John A. Fleming, Director of the Department of Terrestrial Magnetism. In this apparatus the specimen is rotated in a space free of magnetic-field disturbance, obtained by neutralizing the Earth's field and shielding electrostatically from power circuits. The resulting current is amplified and measured. A description of the apparatus, with calculation of sensitivity, has been published by E. A. Johnson and A. G. McNish (5).

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[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 882.

For measurement of suceptibility there was used an apparatus developed by R. B. Sosman at the Geophysical Laboratory, Carnegie Institution of Washington. The apparatus was located at the Research Laboratory of the U. S. Steel Corp., Kearny, N. J., where, through the courtesy of John Johnston, R. B. Sosman, and J. B. Austin, permission was kindly given for its use. The principle employed is measurement of the vertical pull exerted on the specimen when suspended in a field of known strength. The specimen is attached to one arm of a sensitive balance and is suspended near the top of a solenoid. The weight is obtained with and without a current of fixed strength flowing in the solenoid, the two weighings being made consecutively without touching the specimen. A description of the apparatus, with discussion of the calibration and sensitivity, has been given by R. B. Sosman and J. B. Austin (10).

PREVIOUS WORK IN THE FIELD

There has been but little published work bearing on the effect of iron on the magnetic properties of non-ferrous alloys. None of it has been concerned with the suitability of specifications of iron content, and no data have been available that would aid in setting maximum limits for iron as impurity in alloys used for magnetic instruments. Almost no work has been done on the effect of iron in alloys other than binary brass and no comparison of magnetism in different types of copper alloys has been possible.

Two papers may be mentioned as giving some data concerning magnetism due to iron as impurity in brass. Both deal only with binary brass. Kuzenov (7), in Russia, prepared four groups of pure brasses containing about 10, 20, 30, and 40 per cent zinc, respectively. To these he added iron in various amounts ranging from 0.1 to 1.2 per cent. He reported magnetic measurements on these in the cast, rolled, and heat-treated conditions. C. S. Smith (9) employed measurements of remanent magnetic moment to study the precipitation of iron from solid solution in alpha and in beta brass. He investigated the effects of different quenching and annealing temperatures and of cold rolling. He worked only with 70-30 and 53-47 brass. His paper contains numerous graphs, but in only three is magnetism plotted against percentage of iron. Many of the tests were made at a single iron content. The paper contains much information that was useful in planning the present investigation, and includes a brief historical account of the development of knowledge of magnetism in brass.

GENERAL CONSIDERATIONS REGARDING EFFECT OF IRON ON MAGNETIC PROPERTIES OF NON-FERROUS ALLOYS

The magnetic properties of copper alloys are affected by a considerable number of factors, some of major importance and some having only minor effect. These include the following: (1) amount of iron contained as impurity and the form in which it exists, (2) heat treatment, (3) mechanical treatment, (4) segregation, (5) casting conditions, with particular reference to cooling rate, (6) size and shape of the metal object, (7) aging (for the higher iron contents, if above ordinary atmospheric temperature), (8) particle size of precipitated iron and grain size of the alloy and (9) temperature of the alloy in service.

It was the initial purpose of the investigation to study as many of the important factors as possible. While it was obvious that many of the factors would be interrelated, it was desired to study first those which would be of most importance from the standpoint of instrument construction and service. Because iron is strongly magnetic, and since the presence of some iron as impurity is difficult to avoid in commercial alloys, it was to be expected that presence of iron would be the principal cause of the magnetism encountered. Eventually the investigation included several other fac-

TABLE I.—LIST OF ALLOYS TESTED—NAMES AND SPECIFICATION NUMBERS.

Test Number of Alloy	Alloy	A.S.T.M. Specification			Test Specification Number	Nominal Composition, per cent				Test Rating (See Tables XI, XII)
		Designation	Alloy	Iron, maximum per cent		Cu	Sn	Pb	Zn	
					CAST ALLOYS					
No. XIII	High-tin Bronze	B 22	A	0.25	...	80.5	19	...	(P0.5)	Poor
No. X	Composition G	B 143	1B	0.15	46M6(INT)	88	8	...	4	Poor[a]
No. XV	Commercial G	B 143	2B	0.25	...	87	8	1	4	Fair
No. IX	Composition M	B 143	2A	0.25	46B8h	88	6	1.5	4.5	Fair
No. I	Ounce Metal	B 145	4A	0.30	QQ-B-691a (2)	85	5	5	5	Good
No. II	Valve Composition	B 145	5A	0.40	QQ-B-691a (11)	81	3	7	9	Good
No. VIII	High-copper Yellow Brass	B 146	6A	0.60	46B11g (II)	72	1	3	24	Poor
No. III	Commercial Yellow Brass	B 146	6B	0.75	QQ-B-621 (B)	67	1	3	29	Good
No. XI[b]	60–40 Yellow Brass	B 146	6C	0.75	47B2(INT)(I)	61	1	1	37	Poor
No. IV	High-strength Manganese Bronze	B 147	8B	[c]	QQ-B-726b (B)	[d]	...	...	...	Very poor
					WROUGHT ALLOYS					
No. XVIII	Copper (electrolytic)	B 152	A	[e]	...	99.9	...	...	...	Poor
No. XVI	Beryllium Copper	B 194	...	[f]	FXS 408	98	...	...	(Be 2)	Poor[g]
No. VII	5 per cent Phosphor Bronze	B 139	A	0.10[h]	QQ-B-746 (A)	95	5	...	...	Poor
No. XII	Aluminum Bronze	B 169	C	0.50	QQ-B-666 (A)	92	...	...	(Al 8)	Best
No. V	Yellow Brass	B 36	8	0.05	QQ-B-611a (C)	67	...	...	33	Poor
No. VI	Free-cutting Brass Rod	B 16	...	0.15	QQ-B-611a (B)	60	...	3	37	Poor
No. XI	Naval Brass	B 21	A	0.10	47B2	62	0.5	...	36.5	Poor
No. XVI	Nickel Silver	B 151	C	0.25	QQ-N-321 (B)	62	(Ni 18)	1	19	Best
No. XVII	Nickel-copper Alloy	B 127	...	2.50	QQ-N-281	Rem.	...	...	(Ni 66)	Very poor
No. XIX	Monel Sheet	B 127	...	2.50	...	Rem.	...	...	(Ni 66)	Very poor

[a] Based on limited amount of data.
[b] Material was for normally wrought alloy, but tested also as casting.
[c] Range 2.0 to 4.0 iron. Not tested with lower iron.
[d] Analysis of specimen: 64.0 Cu, 23.2 Zn, 0.2 Pb, 2.2 Fe, 3.5 Mn, 7.5 Al.
[e] No specification requirement, but no commercial copper contains as much as 0.004 Fe.
[f] Ni + Co + Fe = 0.60 per cent max. (Fe alone is usually 0.15 to 0.40 per cent).
[g] Tested only at 0.09 Fe. Rated poor because of relatively high magnetism at this iron content and difficulty of securing lower iron.
[h] For rods over 1.25 in., 1.25 per cent Fe max.

tors, but at the outset the work was centered on the principal one of the effect of iron.

It has been shown by a number of other investigators that the effect of iron is greatly dependent on the form in which the iron exists in the alloy. If iron is dissolved and exists in solid solution in face-centered cubic copper or copper alloy, virtually all of its magnetism is lost and the resulting solid-solution alloy is at most only slightly magnetic. If the iron separates from solution and exists in the body-centered cubic form, ferromagnetism normally results. Although magnetism is not generally dependent on crystal form, since it occurs in metals and alloys having different types of lattice, magnetism in iron is commonly related to its lattice structure. It is generally believed that iron may separate from a face-centered cubic solution, as in copper alloys, without transforming to the body-centered lattice, remaining therefore at least partly in paramagnetic form (**2**, **3**, **4**, **9**). It may then become relatively strongly magnetic through subsequent plastic deformation, which probably changes its crystalline form. Only a little cold work may be needed to cause a large increase in magnetism. The same result may be brought about in some cases by prolonged heating.

TABLE II.—CHEMICAL ANALYSES OF ALLOYS TESTED.

Test Number of Alloy	A.S.T.M. Specification		Chemical Analysis, per cent				
	Designation	Alloy	Cu	Sn	Pb	Zn	Other Alloying Elements
			CAST ALLOYS				
No. XIII	B 22	A	81.2	18.4	0.3	...	...
No. X[a]	B 143	1B	87	9	0.1	4	...
No. XV	B 143	2B	87.2	7.4	0.9	4.4	...
No. IX	B 143	2A	87.7	5.6	1.7	5.0	...
No. I	B 145	4A	85.2	4.9	5.0	4.9	...
No. II	B 145	5A	80.7	2.8	7.3	9.2	...
No. VIII	B 146	6A	71.7	1.3	3.6	23.4	...
No. III	B 146	6B	68.4	0.7	2.2	28.7	...
No. XI	B 146	6C	62.7	0.6	0.1	36.6	...
No. IV	B 147	8B	64.0	...	0.2	23.2	Fe 2.2, Mn 3.5, Al 7.5
			WROUGHT ALLOYS				
No. XVIII[a]	B 152	A	99.9	...	...	...	...
No. XVI	B 194	...	97.7	...	...	...	Be 1.9, Ni 0.4
No. VII	B 139	A	94.6	4.6	...	...	P 0.36
No. XII	B 169	C	91.6	...	...	...	Al 8.4
No. V	B 36	8	66.5	...	0.1	33.4	...
No. VI	B 16	...	60.3	...	3.4	36.3	...
No. XI	B 21	A	62.7	0.6	0.1	36.6	...
No. XIV	B 151	C	65.6	...	0.8	15.4	Ni 18.2
No. XVII	B 127	...	32.5	...	...	...	Ni 66.1, C 0.9. Also Mn 0.8 in some samples
No. XIX[a]	B 127	...	28	...	...	...	Fe + Mn, 5; Ni 67

[a] Nominal composition; not analyzed.

If iron forms a chemical compound with another element in an alloy, the properties of the compound may be wholly different from those of iron and magnetism may be nearly absent. This occurs in aluminum alloys, where iron forms a compound that is almost nonmagnetic; these alloys have been shown by Mason (**8**) to exhibit only slight paramagnetism even when containing as much as 8 per cent iron.

EXPERIMENTAL PLAN AND COPPER ALLOYS INCLUDED IN THE INVESTIGATION

Measurements of magnetic susceptibility and magnetic moment were made on specimens of 19 copper alloys. These comprised 10 cast and 10 wrought alloys, one composition appearing in both groups. The alloys tested are listed in Table I, which gives for each its investigation number, name classification, A.S.T.M. specification number, the maximum tolerance of iron content permitted in the listed specification, the specification number under which the material tested was made or supplied (Federal, Navy Department, or Bureau of Ships), and the nominal composition. The test rating as discussed later is also listed in this table for easy reference. In Table II are given the actual chemical analyses of the samples of each alloy tested.

The effect of iron content was studied in sixteen of the alloys by adding to the alloy various small percentages of iron ranging from nearly zero to a little above the maximum tolerance of iron given in the specification, so that data could be obtained for plotting graphs of variation of susceptibility and magnetic moment with iron content. Data for cast alloys were obtained on specimens as cast, and data for wrought alloys were obtained both on specimens as cast and as rolled. After making the magnetic measurements on these specimens, they were then heat-treated and the measurements repeated in the heat-treated condition. One heat-treatment was designed to show the possibility of lowering the magnetism by putting the iron largely in solid solution. This was accomplished by heating the specimens 24 hr. at a temperature above that required for complete solid solubility and then quenching from that temperature in cold water. For most of the alloys the temperature used for this solution-quenching treatment was 800 C.; in some cases it was higher.

Some of the cast alloys and all of the wrought alloys were also subjected to annealing treatments. In the case of cast alloys, some of the specimens that had been given the above solution-quenching treatment were then reheated to 500 C. for 24 hr. and slowly cooled. Other specimens were annealed in the same way at 650 C. In the case of wrought alloys, rolled specimens were annealed at 300 C. and at 500 C. For heat treatment the specimens were packed in powdered charcoal in a covered nichrome box and heated in a small muffle furnace provided with automatic temperature control.

In order to have adequate knowledge of the variation or "spread" in the measurements between individual specimens, from two to nine specimens were prepared for testing of each iron content in each condition. The usual number for the as-cast or as-rolled conditions was four to seven; for annealed specimens usually only two were used.

Of the above alloys, samples for testing were received from Government or commercial sources for alloys designated as Nos. VII to XI, XIII, XV, XVI, XVIII, and XIX. Samples of the remaining nine alloys and of No. VIII were made in the Lehigh University laboratory from high-grade metals. No. VIII is included in both categories; two lots of this alloy were prepared and tested. Melting was done either in clay-graphite crucibles in a gas-fired crucible furnace or in pure graphite crucibles in a 35-kva. Ajax-Northrup induction furnace, depending on the components of the alloy. Melts were made under charcoal in a covered crucible.

From the samples of beryllium copper and monel metal, test specimens were cut directly without remelting, these two alloys being tested without variation of iron content. All of the other alloys were melted, the quantity of each varying from about 13 to 25 lb. This quantity was then divided into several portions, usually six, by pouring into smaller clay-graphite crucibles. From one of these, test specimens were prepared without addition of iron. The others were remelted and iron dissolved in the melt in the required amounts. The iron was introduced in the form of fine iron wire (No. 36 wire, used for analytical standardization, 99.8 per cent Fe), which dissolved almost instantly when thrust down into the melt with the graphite rod used for stirring. In the whole melting and casting operation there was a loss of several per cent of the iron added, this loss increasing with the amount of iron, and although the loss was regular and predictable within limits, it was not possible to fix the iron content of the ingots exactly, and this was accordingly determined by chemical analysis.

From these melts cylindrical ingots were cast in pure graphite molds which had been heated just to redness. The casting conditions were not closely controlled, but did not vary greatly between one sample and another or one alloy and another. The effect of variations in casting conditions over a wide range was studied in another portion of the investigation. The results of this study indicated that the effect of variations of ordinary magnitude, such as those resulting from the regular procedure, was too small to affect the significance of the results, and yet might in some cases be large enough to account for some irregularities appearing in the graphs.

For specimens to be tested in the as-cast condition, the size of the ingots was 3.5 in. long by 0.5 in. in diameter. For specimens to be tested after cold rolling, the size of the ingots was 5 in. long by 1 in. in diameter. From the smaller ingots, disk specimens 0.4 in. high and 0.5 in. in diameter were machined, usually only three from each ingot being taken so as to avoid the tops and bottoms. It was rarely necessary to machine any metal from the sides of the cylindrical ingot that were in contact with the graphite mold. The sides were clean and bright and the slight tarnish that formed while cooling in the mold was readily removed by pickling. The larger ingots were cold rolled in power laboratory rolls to a total reduction of 80 per cent; two intermediate anneals were used and the reduction after the last anneal was 50 per cent. The rolled metal was in the form of a strip 0.20 in. thick. Disks of this thickness and 0.5 in. in diameter were cut from these so that two of the disks placed together in the testing apparatus gave a specimen of the same size as used for the cast specimens. All specimens were pickled in nitric acid and washed before making the magnetic measurements.

Chemical analyses were made in the laboratory of the Frankford Arsenal. It was not feasible to analyze each specimen. The usual procedure was to analyze one specimen of each nominal iron content, using a specimen that had already been measured magnetically and thus was known to be representative of the group. Besides the determination of iron, specimens of each alloy were also analyzed for all of the other principal components, and spectrographic analyses of these specimens were made to insure virtual absence of impurities other than iron.

At the outset, the question of non-uniformity or segregation of iron in the ingots was considered. Samples were obtained by drilling ingots at several points across a section both horizontally and vertically. No appreciable non-uniformity was found by chemical analysis of these samples. Nevertheless it cannot be certain that some non-uniformity did not exist in some of the alloys, and in some cases the iron content of specimens not analyzed may have differed appreciably from the analysis obtained. It is believed that this factor and that of variation in casting conditions would account for such irregularities as appear in the data, and that the precision of the magnetic measurements was well within the limitations imposed by the other factors. The factor of non-uniformity in composition and structure can be largely eliminated by giving each specimen a long homogenizing treatment, but it was undesirable to limit the scope of this investigation by procedure that would require too great an expenditure of time, particularly in view of the objectives directed toward practical usage and war material. The results obtained, the degree of agreement between individual or check determinations of specimens in the same groups, and the agreement of repeated measurements on the same specimens made in aging tests appear to justify the selection of the plan and methods used.

EXPERIMENTAL RESULTS

Because of space limitations, a complete set of measurements is here tabulated for only two alloys. These will serve to illustrate the general plan of the measurements and the "spread" between individual values for that alloy. For the other alloys only averages are given, and the graphs are based on average values. The graphs are drawn as straight lines connecting the average points, because of uncertainty as to whether departure of such points from a smooth curve may be a true departure or may be an apparent one due to the factors mentioned above, and also in some cases because of an insufficient number of points to determine the precise trend of the curve.

TABLE III.—MAGNETIC SUSCEPTIBILITY, χ ($\times 10^6$) OF ALLOY NO. XII.
(Aluminum Bronze, Spec. B 169, Alloy C)

Iron, per cent	As Cast	Cast Specimens Quenched from 870 C.	As rolled	Rolled Specimens Quenched from 870 C.	Rolled Specimens	
					Annealed at 300 C.	Annealed at 500 C.
0.01	−0.15	−0.15	−0.23			
	−0.15		−0.19		−0.08	
	+0.04	−0.12	−0.19			−0.04
	0.05		−0.19			−0.04
			−0.15	−0.12		
			−0.15	−0.08		
			−0.15		−0.12	
0.12	−0.15		−0.11	0.00		
	−0.15	0.00	−0.11		2 2	
	−0.15		−0.07			8.5
	−0.11	−0.04	−0.07			
			−0.04	−0.08		
			−0.04		4.3	
			−0.04			7.4
0.19	2.1	0.12	+1.5		13	
	2.1		1.6		12	
	3.6	0.08	1.7			58
	3.7		1 7			66
			1.7	+0.08		
			2.0	0.08		
			2.1			
0.38	8.8		44	0.26		
	9.5	0.15	45	0.26		
	10.5	0.19	45			
	11.1		46		65	
			47		66	
			48			174
			49			168
0.61	19		252			593
	21	1.0	253			549
	22	0.9	256		324	
	23		261		330	
			266	1.4		
			269	1.4		
			269			
1.64	99		969	52		
	100	17	985			
	107	15				
	111					

Alloy No. XII (Aluminum Bronze):

The complete set of magnetic measurements obtained for aluminum bronze containing copper and aluminum in the ratio of 91.6 to 8.4 is given in Tables III and IV. In these tables the data for a specimen tested under more than one condition are placed on the same line, so that the change resulting from the change of conditions is clearly shown. This applies separately, however, to the cast specimens and to the rolled specimens, since it was not possible to roll the same specimen that had been measured as cast. A minus sign indicates that the specimen was diamagnetic.

The wide range covered in the measurements is notable, with susceptibilities varying from -0.23 to 985 ($\times 10^{-6}$) and magnetic moments from less than 0.01 to 610 ($\times 10^{-3}$). No attempt has been made to include the higher values in the range of the graphs, since these values are far outside tolerable limits.

The "spread" of the individual measurements was less in the case of this alloy than for most of the others. In this case and in most of the others the more satisfactory magnetic behavior was apparently accompanied by greater homogeneity in the specimens, which would be expected from a greater solid solubility for the iron content.

In the case of this alloy the effect of rolling was small up to 0.19 per cent iron. Above 0.19 per cent, rolling greatly increased both magnetic properties, the increase becoming extremely large at the high iron contents.

The effect of the solution-quenching treatment was pronounced on both cast and rolled specimens, and especially so on the latter. This treatment would be more than usually beneficial on this alloy. The suceptibilities of the rolled specimens containing 0.61 per cent iron were in the highest range before this treatment, but became low after it. The magnetic moments were reduced almost as much.

Except at the lowest iron content, the effect of annealing rolled specimens was to bring about a large increase in the magnetic properties, the increase becoming rapidly greater as the iron content increased. Annealing at 500 C. in all cases caused greater rises, usually much greater, than annealing at 300 C.

TABLE IV.—MAGNETIC MOMENT, M ($\times 10^3$) OF ALLOY NO. XII.

(Aluminum Bronze, Spec. B 169, Alloy C)

Iron, per cent	As Cast	Cast Specimens Quenched from 870 C.	As Rolled	Rolled Specimens Quenched from 870 C.	Rolled Specimens	
					An-nealed at 300 C.	An-nealed at 500 C.
0.01	0.01	0.01	0.01	0.01		
	0.01	0.01	0.01	0.01		
	0.01		0.01		0.01	
	0.00		0.01		0.01	
			0.01			0.01
			0.01			0.01
			0 01			
0.12	0.01	0.01	0.01	0.01		
	0.01	0.01	0.01	0.01		
	0.01		0.01		1.04	
	0.01		0.01		0 27	
			0.01			3.5
			0.01			4.0
			0.01			
0.19	0.03	0.01	0.83		4.1	
	0.03	0.01	0.81		3.4	
	0.03		0.79			38
	0.03		0.79			51
			0.90	0.01		
			0.97	0.01		
			0.95			
0.38	0.39		34	0.02		
	0.32	0.01	36	0.01		
	0.34	0.01	36			
	0.27		36		54	
			37		55	
			38			153
			39			133
0.61	2.3	0.04	179			
	2.8		179			610
	2.8	0.18	187			531
	2.9		189		258	
			189		264	
			184	1.5		
			187	1.2		
1.64	24		410	12		
	20	1.0	456			
	20	1.3				
	25					

Alloy No. XIV (18 per cent Nickel Silver):

The magnetic properties of this alloy are not as low at low iron contents as those of No. XII, but they increase very slowly with iron content, and are remarkably low at fairly high percentages of iron. Furthermore, the alloy is magnetically very stable, its magnetism being only slightly affected by rolling, by annealing, or by the solution-quenching treatment. The magnetic moments are exceptionally low, their behavior being

TABLE V.—MAGNETIC SUSCEPTIBILITY, χ ($\times 10^6$) OF ALLOY NO. XIV.
(Nickel Silver, Spec. B 151, Alloy C.)

Iron, per cent[a]	As Cast	Cast Specimens Quenched from 800 C.	As Rolled	Rolled Specimens Quenched from 800 C.	Rolled Specimens: Annealed at 300 C.	Rolled Specimens: Annealed at 500 C.
	0.44	0.51	0.37	0.47		
0.01	0.41	0.41	0.40	0.50		
(0.00)	0.34		0.33		0.13	0.44
	0.31		0.40		0.13	0.47
	0.61	0.57	0.53	0.67		
0.05	0.45	0.60	0.60	0.54		
(0.10)	0.53		0.50		0.47	0.61
	0.51		0.54		0.54	0.60
	0.59	0.52	0.66	0.80		
0.11	0 70	0.49	0.59	0.67		
(0.10)	0.63		0.63		0.63	0.81
	0.62		0.64		0.60	1.15
	0.66	0.59	0.87	0.54		
0.21	0.66	0.63	0.84	0.61		
(0.16)	0.59		0.87		1.01	0.64
	0.62		0.77		1.01	0.96
	0.72	0.69	0.84	0.75		
0.33	0.76	0.73	0.84	0.81		
(0.22)	0.69		0.77		0.47	1.09
	0.73		0.87		0.81	1.01
	2.1	1.8	1.6	1.4		
0.63	2.1	1 8	1.7	1.6		
(0.60)	2.1		1.7		1.8	2.3
	2.0		1.7		1.2	2.2

[a] Iron analysis of rolled specimens given by first figure, of cast specimens by figure in parentheses.

even more favorable than that of the susceptibilities. The magnetic properties of aluminum bronze are adversely affected by rolling and also by annealing. On the other hand, rolled specimens of nickel silver annealed at 500 C. showed only slight increases in magnetic properties. In all other alloys for which this test was made, marked increases resulted when their iron contents exceeded 0.05 per cent. (See Tables V and VI.)

COMPARATIVE MAGNETIC PROPERTIES OF THE VARIOUS ALLOYS

The average values obtained in the measurements of susceptibilities and magnetic moments for ten cast alloys, both as cast and after the solution-quenching treatment, are given in Tables VII and VIII. In these tables the alloys are arranged approximately in order of the magnitude of the magnetic properties, the order at 0.10 per cent iron as cast being used in most cases. Because of different rates of increase with iron content, and in a few instances because of irregularities in the data, the order is not the same for other iron contents, but in general there is a decided upward trend in the table from top to bottom as well as from left to right, except at the lowest iron content.

Similarly, Tables IX and X give the results for the measurements of susceptibility and magnetic moment for ten wrought alloys, listed in order of magnitude as rolled. In addition to the data for the rolled condition and as heat-treated after rolling, data are given for the cast condition for comparison, even though these alloys would not be used as castings.

TABLE VI.—MAGNETIC MOMENT, M ($\times 10^3$) OF ALLOY NO. XIV.
(Nickel Silver, Spec. B 151, Alloy C.)

Iron, per cent[a]	As Cast	Cast Specimens Quenched from 800 C.	As Rolled	Rolled Specimens Quenched from 800 C.	Rolled Specimens: Annealed at 300 C.	Rolled Specimens: Annealed at 500 C.
	0.01	0.01	0.02	0.01		
0.01	0.01	0.03	0.01	0.01		
(0.00)	0.01		0.01		0.01	0.06
	0.01		0.01		0.01	0.24
	0.01	0.05	0.01	0.02		
0.05	0.01	0.02	0.03	0.02		
(0.10)	0.01		0.03		0.02	0.03
	0.01		0.03		0.02	0.08
	0.01	0.02	0.03	0.02		
0.11	0.01	0.02	0.03	0.01		
(0.10)	0.01		0.02		0.02	0.23
	0.02		0.07		0.03	0.68
	0.02	0.01	0.01	0.01		
0.21	0.03	0.02	0.01	0.02		
(0.16)	0.01		0.02		0.02	0.02
	0.01		0.01		0.02	0.05
	0.01	0.02	0.01	0.01		
0.33	0.01	0.03	0.02	0.02		
(0.22)	0.01		0.01		0.02	0.03
	0.01		0.02		0.02	0.02
	0.05	0.02	0.07	0.02		
0.63	0.05	0.02	0.01	0.02		
(0.60)	0.07		0.01		0.03	0.02
	0.07		0.02		0.04	0.05

[a] Iron analysis of rolled specimens given by first figure, analysis of cast specimens given by figure in parentheses.

TABLE VII.—MAGNETIC SUSCEPTIBILITIES, χ ($\times 10^6$) OF CAST COPPER ALLOYS.

Test Number of Alloy	0.01 % Fe	0.05 % Fe	0.10 % Fe	0.15 % Fe	0.20 % Fe	0.25 % Fe	0.30 % Fe	0.40 % Fe	0.50 % Fe	0.85 % Fe
AS CAST										
No. I	0.1	0.2	0.4	0.9	1.3	1.7	2.5		8.4	
No. II	0.1	0.3	0.5	1.3	1.9	2.4	1.4	6.9	11	
No. III			0.6	0.9	1.2	2.6	3.9	6.3	17	67
No. XV		0.2	1.6	4.5	6.2	10	15	17	17	
No. XI	0.1		3.2	1.7	7.2	12	17		38	
No. IX			1.3	6.3	17	28	42			
No. X		1.2	3.2	3.4						
No. VIII	0.1	8.0	15	16	17	18	19	67	93	139
No. XIII	0.1	3.5	17	67						
AFTER SOLUTION—QUENCHING TREATMENT										
No. I	0.1	0.1	0.1	0.1	0.3	0.6	0.6		72[a]	
No. II	0.1	0.2	0.2	0.4	0.4	0.5	0.6		4.0	
No. III			0.1	0.2	0.3	0.5	0.6	0.8	2.1	118[a]
No. XV		0.1	0.3	0.4	0.7	1.5	2.3	12	23[a]	
No. XI	−0.2			0.9	11	22	32		75[a]	
No. IX			0.3	0.8	4.0	7.9	12			
No. X		0.1	0.2	1.1						
No. VIII	0.1	0.6	2.9	6.0	7.3	5.9	4.6		43	183[a]
No. XIII	−0.1	2.8	16	8.5						

[a] Increase in magnetism caused by heat treatment due to incomplete solution of iron during solution treatment.

TABLE VIII.—MAGNETIC MOMENTS, M ($\times 10^3$) OF CAST COPPER ALLOY.

Test Number of Alloy	0.01 % Fe	0.05 % Fe	0.10 % Fe	0.15 % Fe	0.20 % Fe	0.25 % Fe	0.30 % Fe	0.40 % Fe	0.50 % Fe	0.85 % Fe
AS CAST										
No. I	0.01	0.02	0.04	0.15	0.3	0.6	1.4		10.5	
No. II	0.00	0.02	0.07	0.4	0.7	0.9	0.5	8.5	16	
No. III			0.14	0.2	0.3			9.1	15	20
No. XV		0.01	0.6	2.6	3.4	9.4	17	16	13	
No. XI			0.8	1.0	7.2	13	19		44	
No. IX			1.2	3.6	6.2	10	16			
No. X		2.2	4.2	3.3						
No. VIII	0.01	0.6	2.1	3.7	5.0	5.8	6.5	20	49	43
No. XIII	0.01	1.2	9.7	9.0						
AFTER SOLUTION-QUENCHING TREATMENT										
No. I	0.01	0.01	0.01	0.02	0.02	0.02	0.03		15[a]	
No. II	0.00	0.00	0.01	0.01	0.01	0.01	0.01	2.0	4.0	
No. III	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.6	6.0
No. XV		0.00	0.01	0.01	0.01	0.06	0.10	4.4	11	
No. XI	0.01		0.7	0.5	2.6	4.6	6.7		15	
No. IX	0.00	0.01	0.15	0.2	0.4	0.6	0.8			
No. X		0.01	0.01	0.3						
No. VIII	0.01	0.3	0.6	0.7	0.8	0.9	1.0	1.2	1.9	23
No. XIII	0.01	1.0	0.5	6.0						

[a] Increase in magnetism caused by heat treatment due to incomplete solution of iron during solution treatment.

The data show that all the alloys listed in these tables have very low magnetic properties as cast or as rolled if the iron content is as low as 0.01 per cent. In a few cases a determination was not made at this low iron content, but even in these instances there is no reason to doubt that very low values would be found. Since the measured values represent the lowest range of magnetism that can regularly be obtained in instrument alloys of high purity, it may be concluded that all of these alloys would be satisfactory for instrument construction from the magnetic standpoint as cast if they could be kept free from iron as impurity within the limit of 0.01 per cent.

The solution-quenching treatment has a notably beneficial effect, and if this

TABLE IX.—MAGNETIC SUSCEPTIBILITIES, χ ($\times 10^6$) OF WROUGHT COPPER ALLOYS.

Test Number of Alloy	0.01 % Fe	0.05 % Fe	0.10 % Fe	0.15 % Fe	0.20 % Fe	0.25 % Fe	0.30 % Fe	0.50 % Fe	0.85 % Fe
As Cast									
No. XII	−0.1	−0.1	−0.1	−0.1	2.3	4.8	7.4	16	40
No. XIV	+0.4	+0.5	+0.6	+0.6	0.6	0.7	0.8	1.6	
No. VI	0.0	0.7	11	15	24	35	46		
No. XVIII	−0.2					3.2	5.0	5.0	5.4
No. VII	0.0	3.2	6.8	62	96	115	126		
No. XI	0.1		3.2	1.7	7.2	12	17	38	
No. V	0.1	7.0	23	27					
As Rolled									
No. XII	−0.2	−0.1	0.2	1.3	7.3	16	26	158	430
No. XIV	+0.4	+0.5	0.7	0.8	0.8	0.8	0.9	1.4	
No. VI	0.1	0.4	1.5	2.6	21	51	81		
No. XVIII	−0.1	3.0	6.2	6.1	6.0	11	17		520
No. VII	0.0	1.9	8.8	17	25	31	36		
No. XI	0.1	5.1	9.9	42	75	98	122	220	
No. V	0.1	7.1	34	58					
Treated by Solution-Quenching After Rolling									
No. XII	−0.1	−0.1	0.0	0.1	0.1	0.1	0.2	0.9	12
No. XIV	+0.5	+0.6	0.6	0.7	0.7	0.8	0.9	1.3	
No. VI	0.0	0.1	1.7	3.8					
No. XVIII	−0.1	−0.1		0.1	0.1	0.2	0.3	0.9	2.1
No. VII	0.0	14	29	43	54	61			
No. XI	−0.1	1.2	3.3	1.7	0.2	5.6	11	33	
No. V	−0.1	0.2	0.6	1.0					

TABLE X.—MAGNETIC MOMENTS, M ($\times 10^3$) OF WROUGHT COPPER ALLOYS.

Test Number of Alloy	0.01 % Fe	0.05 % Fe	0.10 % Fe	0.15 % Fe	0.20 % Fe	0.25 % Fe	0.30 % Fe	0.50 % Fe	0.85 % Fe
As Cast									
No. XII	0.01	0.01	0.01	0.01	0.03	0.11	0.2	1.6	7.5
No. XIV	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.04	
No. VI	0.05	0.6	4.2	4.6	7.3	11	15		
No. XVIII	0.02					2.5	3.7	3.8	7.8
No. VII	0.01		9.0	44	83	112	117		
No. XI			0.8	1.0	7.2	13	19	44	
No. V	0.01		4.8	12					
As Rolled									
No. XII	0.01	0.01	0.14	0.7	6.1	15	23	114	240
No. XIV	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.03	
No. VI	0.03	0.9	3.7	3.0					
No. XVIII	0.03	0.9	1.8	4.0	6.4	10	15		510
No. VII	0.01		6.4	14	23	30	28		
No. XI	0.3	1.0	7.4	40	73	81	89	123	
No. V	0.02		13	23					
Treated by Solution-Quenching After Rolling									
No. XII	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.7	4.0
No. XIV	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	
No. VI	0.07	0.03	2.3	1.4	2.0	3.6	5.3		
No. XVIII	0.02				0.2	0.03	0.03	0.02	0.03
No. VII	0.04		5.5	11	16	21	24		
No. XI	0.01	0.15	0.2	0.11	0.02	1.2	2.4	7.2	
No. V	0.01	0.07	0.2	0.3					

treatment were given, most of the cast alloys would have nearly as low magnetic properties at 0.10 per cent iron as they have at 0.01 per cent iron without heat treatment. Some of the rolled alloys are also greatly benefited. Some compositions respond to this treatment much more than others.

Of the various major alloying elements—zinc, tin, lead, aluminum, and nickel—only nickel shows any tendency to increase magnetism in the absence of iron, and in the case of nickel the amount of magnetism produced is very small, at least up to the percentage contained in 18 per cent nickel silver.

A comparative rating of the alloys may be made with reference to the increase of magnetism produced by increasing iron content, and particularly with reference to the maximum percentage of iron that may be present without causing unduly high magnetic properties. In these respects the alloys differ greatly. The question as to how high the magnetic properties may be without causing the alloy to be unsuitable for magnetic instrument construction is uncertain, but for the purposes of discussion it is necessary to set some arbitrary limit beyond which it appears that the magnetic properties might be unsatisfactory. The actual magnitude of the limit in practice would obviously depend on the purpose for which an instrument was to be used, its design, and the mechanical and physical conditions under which the alloy would exist in the instrument. No data are available as to the magnitude of susceptibility or magnetic moment actually occurring in the materials of instruments that have given trouble in service. If such data were available they would vary with instrument design, particularly as regards shape and bulk of structural parts and their spacing with reference to the location of the compass needle or other magnetic part; they would depend also on the degree of precision required in the instrument. The present study showed that in some alloys the magnetic properties rise only slowly with increasing iron content and others very rapidly. A pattern of variation found in certain alloys that are often used for instrument construction was one of slight increase only at very low percentages of iron, followed by a faster rate, and finally by a very steep rise at higher iron percentages. It is probable that magnetic properties in the last range would cause trouble in many instances; that those in the intermediate range might cause trouble in some instances; and that those in the first range would be those found in satisfactorily functioning instruments. The data obtained suggest that values of 1.0×10^{-6} for susceptibility and 1.0×10^{-3} for magnetic moment would be suitable as a basis for comparison. These limits fall in the lower and flatter portions of the curves, Figs. 1 and 2. On this basis the alloys may be grouped as in Tables XI and XII.

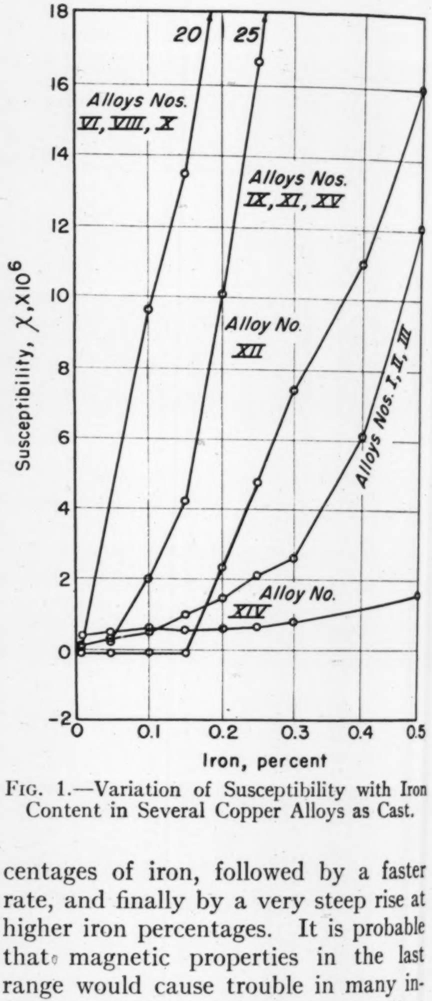

FIG. 1.—Variation of Susceptibility with Iron Content in Several Copper Alloys as Cast.

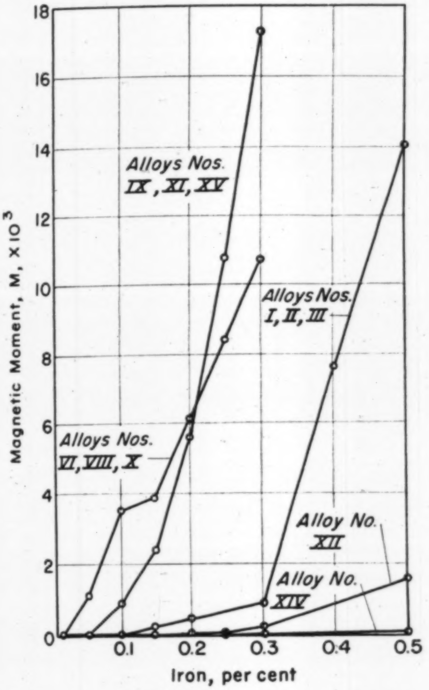

FIG. 2.—Variation of Residual Magnetic Moment with Iron Content in Several Copper Alloys as Cast.

TABLE XI.—RELATIVE SUITABILITY OF CAST COPPER-BASE ALLOYS FOR MAGNETIC INSTRUMENTS.

Rating	Test Number of Alloy	Alloy Name and Specification
		AS CAST
Good	No. I....	Ounce metal, 85:5:5:5 (B 145, 4A)
	II....	Valve composition (B 145, 5A)
	III....	Commercial yellow brass (B 146, 6B)
Fair	IX....	Composition M (B 143, 2A)
	XV....	Commercial G (B 143, 2B)
Poor	VIII....	High-copper yellow brass (B 146, 6A)
	X....	Composition G (B 143, 1B)
	XI....	60:40 yellow brass (B 146, 6C)
	XIII....	High-tin bronze (B 22, A)
Very poor	IV....	High-strength manganese bronze (B 147, 8B)
IF HEAT-TREATED BY SOLUTION-QUENCHING TREATMENT		
Best	No. I....	Ounce metal, 85:5:5:5 (B 145, 4A)
	II....	Valve composition (B 145, 5A)
	III....	Commercial yellow brass (B 146 6B)
	XV....	Commercial G (B 143, 2B)
Good	IX....	Composition M (B 143, 2A)
	X....	Composition G (B 143, 1B)
Poor	VIII....	High-copper yellow brass (B 146, 6A)
	XI....	60:40 yellow brass (B 146, 6C)
	XIII....	High-tin bronze (B 22, A)
Very poor	IV....	High-strength manganese bronze (B 147, 8B)

The magnetic properties of the alloys listed as "good" remained very low up to iron contents a little above 0.10 per cent, and did not begin to rise rapidly until iron exceeded 0.30 per cent. The alloys listed as "fair" were in the lowest range at iron contents as high as 0.06 per cent, but were above this range at 0.10 per cent iron as regards susceptibility. Their magnetic properties began to rise rapidly at iron contents around 0.15 per cent.

The alloys listed as "poor" are so designated because their magnetic properties rise rapidly at iron contents only a little above 0.02 per cent, becoming unsuitably high at 0.1 per cent iron or less. These alloys would be satisfactory if carefully made from high-grade virgin metals, but are poor in the sense that they would be definitely unreliable if one could not be sure that their iron contents were as low as 0.01 or 0.02 per cent.

Alloys designated Nos. IV, XVII, and XIX are omitted from Tables VII to X because these alloys were found to have such high magnetic properties as to be unsuitable for instrument construction under any conditions. Alloy No. IV contains iron as a specified component in the amount of 2.0 to 4.0 per cent, and No. XIX is also necessarily high in iron (up to 3.0 per cent). Alloys Nos. XVII and XIX contain about 66 per cent nickel. The susceptibilities of alloys Nos. IV and XVII with different contents of iron and manganese ranged from 280 × 10^{-6} to 2160 × 10^{-6}. The susceptibility of No. XIX (monel

TABLE XII.—RELATIVE SUITABILITY OF WROUGHT COPPER BASE ALLOYS FOR MAGNETIC INSTRUMENTS.

Rating	Test Number of Alloy	Alloy Name and Specification
		AS ROLLED
Best	No. XII	Aluminum bronze (B 169, C)
	XIV	18 per cent nickel silver (B 151, C)
Poor	V	Yellow brass (B 36, 8)
	VI	Free-cutting brass rod (B 16)
	VII	5 per cent phosphor bronze (B 139, A)
	XI	Naval brass (B 21, A)
	XVI	Beryllium copper (B 194)
	XVIII	Copper, electrolytic (B 152, A)
Very poor	XVII	Nickel-copper alloy (B 127)
	XIX	Monel sheet (B 127)
		IF HEAT-TREATED BY SOLUTION-QUENCHING TREATMENT
Best	No. XII	Aluminum bronze (B 169, C)
	XIV	18 per cent nickel silver (B 151, C)
	XVIII	Copper, electrolytic (B 152, A)
Good	V	Yellow brass (B 36, 8)
Poor	VI	Free-cutting brass rod (B 16)
	VII	5 per cent phosphor bronze (B 139, A)
	XI	Naval brass (B 21, A)
	XVI	Beryllium copper (B 194)
Very poor	XVII	Nickel-copper alloy (B 127)
	XIX	Monel sheet (B 127)

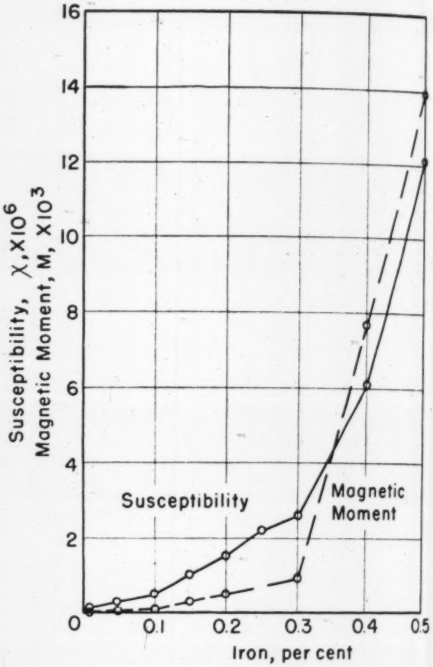

FIG. 3.—Comparative Variation of Susceptibility and Residual Magnetic Moment with Iron Content, Average of Three Common Casting Alloys, Nos. I, II, and III.

sheet) was too high to be determined accurately with the apparatus used, but a value in the neighborhood of 46,000 $\times 10^{-6}$ was recorded.

Figures 1 and 2 are graphs of the susceptibilities and magnetic moments plotted against iron content from some of the data in Tables VII to X. Separate lines are plotted for Alloys XII and XIV, while the other lines represent group averages typical of the ratings "good," "fair," and "poor," respectively, from right to left. These graphs show clearly the pattern followed. There is first a slow increase in the magnetic property with increasing iron content, and finally a steep rise. The point at which the rapid increase begins moves further and further to the left as the alloy becomes less and less satisfactory from the magnetic standpoint. The region of slow increase disappears entirely for the group listed as "poor," where the rapid increase begins virtually at the lowest iron contents. In between the regions of slow and rapid rise there is a transition which may or may not be regarded as a separate region. Actually the regions merge into one another without necessarily any definite limits or sharp breaks, so that in some cases at least the lines may be plotted as smooth curves. In Fig. 3, for the average of alloys Nos. I, II, and III as cast, susceptibility and magnetic moment are plotted in the same graph so as to show their comparative trends for this group of alloys. In this group the magnetic moments rose more slowly than the susceptibilities at first and then more rapidly, so that the curves crossed. This trend is not typical, however; in many alloys the rate of rise in magnetic moment continues to be less

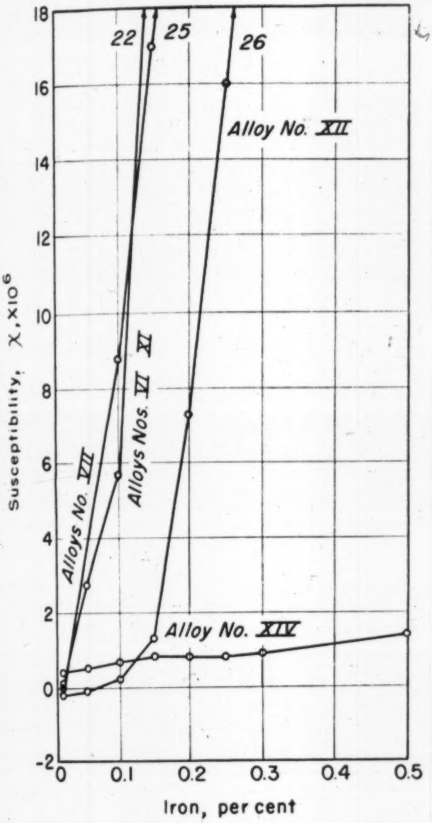

FIG. 4.—Variation of Susceptibility with Iron Content in Several Copper Alloys after Cold Rolling.

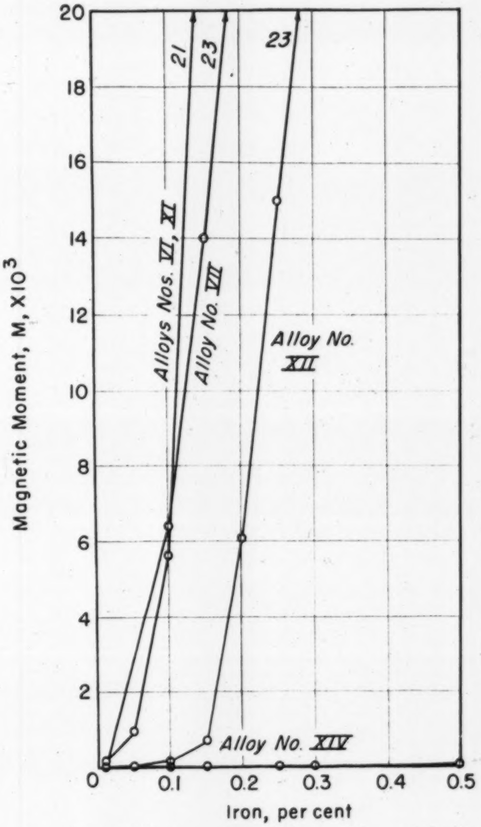

FIG. 5.—Variation of Residual Magnetic M ment with Iron Content in Several Copper Alloys after Cold Rolling.

and less steep as compared with rate of rise in susceptibility.

Figures 4 and 5 are similar plots for alloys as rolled. In most cases the rise in magnetic properties begins at lower iron contents and occurs more steeply in the rolled than in the cast conditions. The reverse is true, however, in the case of some alloys. Number XIV is an example of an alloy having lower magnetic properties as rolled than as cast, particularly as regards magnetic moment. Alloy No. VII is a further example as regards both magnetic properties.

Figure 6 compares the trends of susceptibility and magnetic moment for alloy No. XII as rolled. In this case the curves nearly coincide.

Figure 7 shows the effect of the solution-quenching treatment on three cast alloys, the data for Nos. I, II, and III being plotted separately in the cast condition and also after solution-quenching. Similarly, Fig. 8 shows the effect of this heat-treatment on two wrought alloys and rolled electrolytic copper. Here it is seen that the graphs for nickel silver are nearly the same in both conditions, while a tremendous difference is caused by the treatment in the cases of aluminum bronze and of electrolytic copper.

In summary, for copper-base alloys of

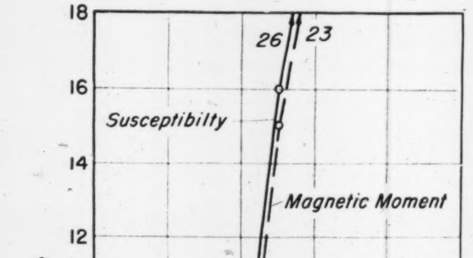

FIG. 6.—Comparative Variation of Susceptibility and Residual Magnetic Moment with Iron Content in Aluminum Bronze Alloy No. XII (Copper: aluminum 91.6/8.4) after Cold Rolling.

certain compositions, it is believed that magnetic properties well within the lowest range can in practice be secured either (1) by use of highest quality metal with proper care to avoid contamination, or (2) by use of somewhat lower quality metal if the solution-quenching treatment is employed. Specifications for iron contents should be such as to yield magnetic properties well within the lowest range.

PRACTICAL SIGNIFICANCE OF THE MAGNETIC DATA

In order to observe qualitatively the possible effect of magnetism in instrument alloys in causing errors in instrument functioning, certain disk specimens that had been used for the magnetic measurements were placed face down on the glass top covering the compass of a surveying instrument. The specimens were then moved over the compass needle and it was observed that the specimens of high iron contents were sufficiently strong in magnetism to cause the needle to follow the specimen through a complete circle, while specimens of low iron contents caused no visible deflection of the needle.

Following this observation, a series of measurements was made to correlate known values of susceptibility and magnetic moment with degrees of deflection of the needle from its normal north-south position that would be produced by moving the specimen over it. The disk specimen, 0.4 in. thick and 0.5 in. diameter and weighing about 10 g., rested on the glass above the tip of the needle and no more than one-half inch from it. The compass case measured $4\frac{3}{4}$ in. in diameter. The specimen was then moved slowly over the division scale of the compass and the maximum distance that the needle would follow the specimen was read in degrees of deflection. The specimens used were those of which the susceptibilities and magnetic moments had previously been measured, so that data were obtained for plotting the magnetic property against maximum deflection of the compass needle. The results are shown in Figs. 9 and 10.

It is seen in Fig. 9 that the first deflection visible with a magnifying glass was at about 4.5×10^{-3} c.g.s. units of magnetic moment. At a moment of 35×10^{-3} there was a deflection of over 9 degrees.

In Fig. 10 susceptibilities are plotted against needle deflection both for specimens of which the susceptibility had been measured and which had therefore

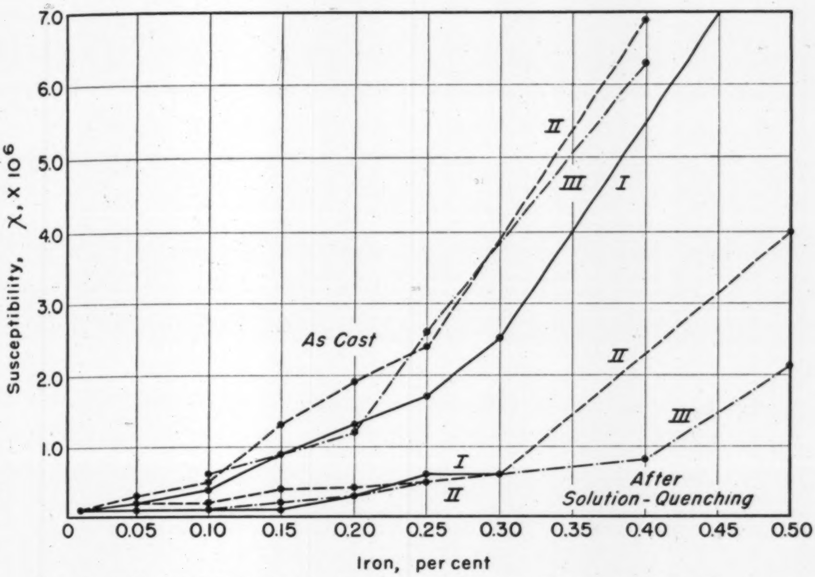

FIG. 7.—Effect of the Solution-quenching Treatment on Certain Cast Alloys.

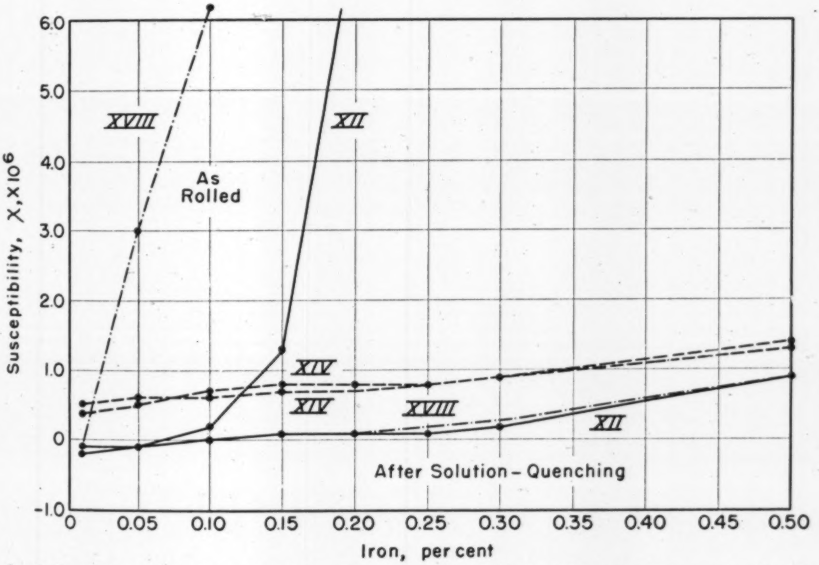

FIG. 8.—Effect of the Solution-quenching Treatment on Certain Wrought Alloys after Rolling.

been magnetized in the field of 436 gauss, and for unmagnetized specimens of which the susceptibilities were approximately known because the specimens were cut from the same ingot as those of which the susceptibilities had been measured. While the curves in this figure, particularly for the magnetized specimens, are considerably more irregular, it is indicated that the first visible deflection for

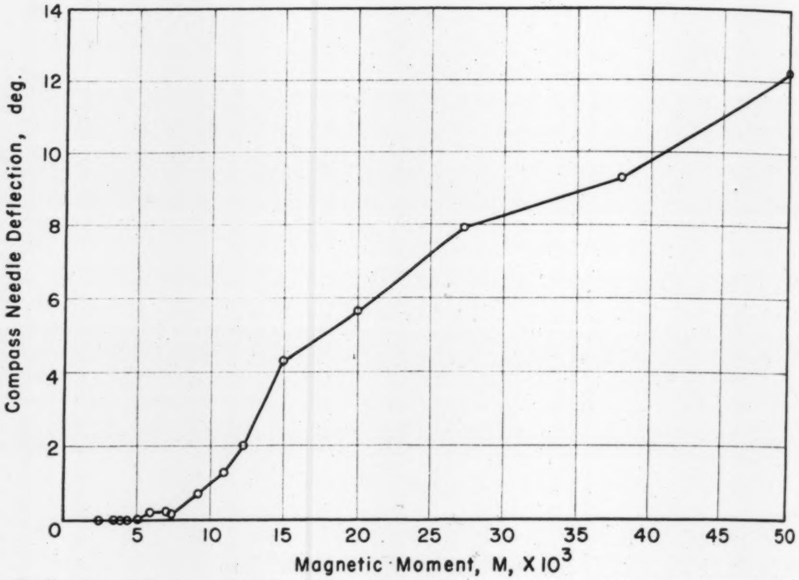

FIG. 9.—Deflection of Compass Needle by Specimens of Copper Alloys of Known Magnetic Moment.

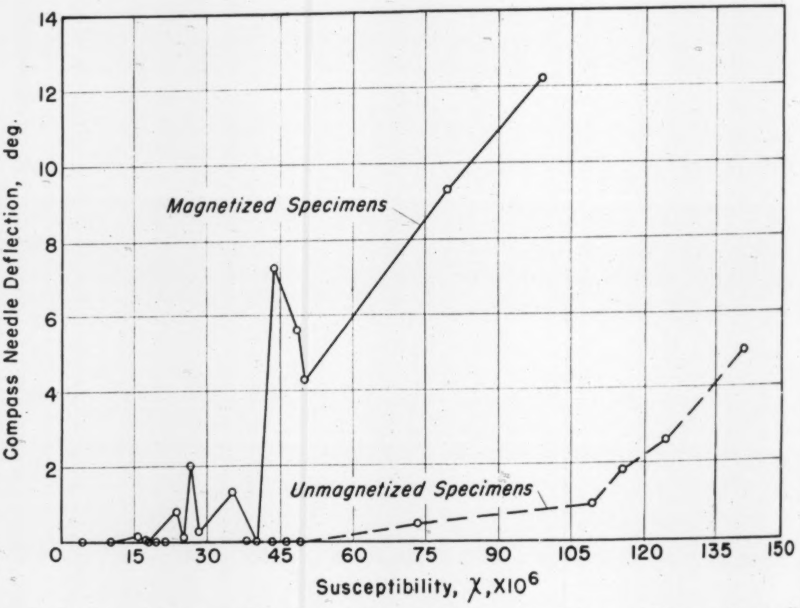

FIG. 10.—Deflection of Compass Needle by Specimens of Copper Alloys of Known Susceptibility Magnetized and Unmagnetized.

the magnetized specimens was at a susceptibility of about 10 × 10^{-6}, and for the unmagnetized specimens at about 45 × 10^{-6}. The irregularity in the graph for magnetized specimens is probably due to difference in residual magnetization at the time the test was made, since these specimens were selected without regard to the time elapsed after the susceptibility had been determined.

These data apply only to the dimensional conditions of the particular instrument used in the test and the manner of its use, and are therefore not applicable in a quantitative way to other instruments. It is not suggested that a test of this kind, even if standardized, would be suitable as a means of fixing tolerable limits of magnetic properties in instrument alloys. It is believed, however, that a magnetic moment or susceptibility of such magnitude as to produce in this way a visible deflection in any compass would not be tolerable in instruments of precision, and that accordingly limits for the magnetic properties must be below the above figures for the first visible deflection, namely 4.5×10^{-3} for moment and 10×10^{-6} for susceptibility. While it is not known how much lower the limits should be, the data tend to substantiate the limits of 1×10^{-3} for moment and 1×10^{-6} for susceptibility which were used arbitrarily in connection with the ratings of the different alloys given in Tables XI and XII. These limits were chosen with reference to the curves showing rate of rise in magnetic properties with iron content, falling well within the range of the beginning of more rapid increase. Since they are below, but not greatly below, the values for first visible deflection of the compass needle, they seem to be qualitatively appropriate.

THE EFFECT OF IRON WHEN PRECIPITATED OR UNALLOYED

When iron present in instrument alloys as impurity is precipitated from solid solution, only part of the total iron content is precipitated. The original precipitate is probably in a relatively nonmagnetic form, which will be transformed to magnetic form by plastic deformation (9). The following measurements were made for the purpose of determining the magnetism produced by iron if completely precipitated and transformed (as alpha iron), or of the effect of a bit of iron accidentally included without being alloyed with the copper alloy.

A brass specimen that had been found by measurement to have zero susceptibility was selected. Five pieces of pure iron wire were then weighed out in weights equal to 0.01, 0.02, 0.05, 0.10, and 0.24 per cent, respectively, of the weight of the specimen. The brass specimen with one of the pieces of iron wire placed on it was placed in the coil of the susceptibility apparatus and the pull exerted by the coil determined as in the regular measurements of susceptibility. The test now simulated the condition where all of the iron content of a sample containing that percentage of iron had been completely precipitated as alpha iron and segregated into a single filiform piece. By using the weight of the brass-plus-iron sample in the formula for calculating susceptibility there is obtained a value for this simulated condition, which may be compared with the susceptibility of the brass with a corresponding amount of iron alloyed with it. By using only the weight of the iron wire in the formula, there is obtained an analogous figure for the pure iron present, and although the significance of this latter figure is uncertain because of the ferromagnetic properties of pure iron, values are obtained which are of interest from the standpoint of comparative order of magnitude.

The results of this test are shown in Table XIII and are plotted in Fig. 11. The graph lacks entirely the form characteristic of the copper-base alloys containing alloyed iron; it is in fact a straight line, as would be expected. The

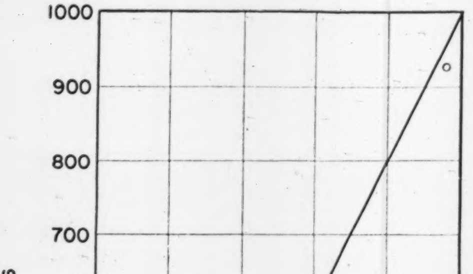

FIG. 11.—Increase in the Susceptibility of Brass with Small Amounts of Unalloyed Iron.

susceptibility values are ten to a thousand fold higher than when the same amount of iron is alloyed in the brass. It is shown that the condition of complete precipitation of iron in magnetic form is never approached in the alloy samples under any of the conditions used in the investigation.

The extent of damage that will result from a minute piece of unalloyed iron is also clearly indicated. As little as 0.01 per cent free iron resulted in very high susceptibility. The presence of unalloyed iron, such as might result from accidental inclusion in manufacture, must therefore be almost entirely avoided. Surfaces likely to contain iron, as from hot rolling, must be ground or turned down or effectively pickled.

TABLE XIII.—SUSCEPTIBILITY, χ ($\times 10^6$) OF NON-MAGNETIC BRASS WITH UNALLOYED IRON.[a]

Weight of Iron Wire, g.	Iron, per cent	Pull of Magnetizing Coil, g.	Calculated Susceptibility	
			Brass plus Iron	Iron Wire Only
0	0	0	0	...
0.0009	0.01	0.00960	37.1	393 000
0.0020	0.02	0.02430	93.8	448 000
0.00495	0.05	0.05775	221	430 000
0.0100	0.10	0.09980	385	367 000
0,0229	0.24	0.24320	926	391 000

[a] Weight of the brass sample is 9.533 g.

CORRELATION OF MAGNETIC PROPERTIES WITH COMPOSITION

No simple explanation of the magnetic behavior of the various copper alloys can be given on the basis of composition. While the effect of iron as impurity overshadows the effects of other factors, the magnitude of the iron effect depends on the form in which the iron is present, which in turn is affected not only by physical factors such as mechanical and thermal treatment, but also by the content of various other elements and the metallurgical form of their content in so far as it affects the form of the iron content. The actual content of the various alloying elements encountered in the group of alloys studied appears to have only a minor direct effect on the magnetic properties, but it has important indirect effects in determining the form in which the iron occurs.

It is well known that variation of magnetism in non-ferrous alloys is directly dependent on phase changes. In solid solutions susceptibility in binary alloys will vary along a smooth curve until a change of phase occurs. In eutectic alloys susceptibility will vary along a straight line between the susceptibilities of the two alloy constituents. When an intermetallic compound occurs a break occurs in the susceptibility curve.

In the present study, involving numerous alloy compositions and various phase relations, it has been strongly indicated that low magnetic properties are to be expected only when the alloy (containing iron impurity) consists of a single phase. The appearance of a second phase appears quite generally to give rise to increased magnetism, although in alloys containing three, four, or five elements in addition to the iron, the exact point of appearance of the second phase could not readily be determined, and time did not permit following this line of investigation. In some cases, however, it was apparent that certain critical ranges of composition occurred in which relatively small changes in the content of some element other than iron caused rather abrupt changes in magnetism. Tin and aluminum may be cited especially in this regard. On the other hand lead, which is nearly insoluble in the copper alloys, had but little effect on the magnetic properties so far as determined by the tests performed.

Alloying of zinc with copper generally caused progressively lower magnetism until the percentages were reached in which the beta constituent might appear. The presence of beta signalized a very large increase in magnetism, and one which was greatly augmented by thermal or mechanical treatment.

Similarly when the limit of the alpha solid-solution range in the copper-aluminum alloys was reached a marked rise in magnetic properties occurred. Thus the very favorable magnetic properties found for alloy No. XII (B 169, C) are not broadly characteristic of the aluminum bronzes. The particular alloy tested was close to the optimum composition. At slightly higher aluminum contents the magnetism would rise considerably, and would probably rise slowly with lower aluminum contents. Also, the alloy tested was binary aluminum-copper, and it was found that the beneficial effect of aluminum was probably limited to alloys containing little zinc or tin.

The advantageous behavior of nickel silver may at first seem surprising in view of the ferromagnetism of nickel. Some effect of its ferromagnetism appears to be visible in the slightly higher susceptibilities found in alloy No. XIV (B 151, C) as compared with a number of the other alloys up to 0.10 per cent iron. It is known, however, that the ferromagnetism of nickel is virtually absent in the copper-nickel solid solutions until the nickel content exceeds about 38 per cent by weight at room temperature; or, stated in another way, ferromagnetism disappears in nickel-copper alloys when more than 40 per cent of the nickel atoms are replaced in solid solution by copper atoms. The effect of nickel in suppressing the ferromagnetic effect of iron in nickel silver at low iron contents is due to its effect on the solid solubility of iron in the alloy. Copper and iron have only slight solubility in each other in the solid state, but as nickel is added to the copper-iron alloy, the solubility of iron in copper and copper in iron are increased. With increased amounts of nickel, the gap in the copper-iron side of the ternary diagram is progressively narrowed and with a sufficient amount of nickel there is only one phase in the ternary Cu-Ni-Fe alloys.

The casting bronzes included in the tests were the following, arranged in order of increasing tin content: Nos. II, I, IX, XV, X, XIII (Alloys 5A, 4A, 2A, 2B, 1B, and B 22 Class A). It will be noted that in Table XI alloys 4A and 5A are rated "good," 2A and 2B "fair," and 1B and B 22 Class A "poor." The appearance of the delta constituent in Cu-Zn-Sn alloys containing iron impurity results in a rapid rise in magnetism. Tin present in amounts of less than about 4 per cent (depending on the zinc content) may have a slightly beneficial effect in lowering magnetism. It is indicated that in order to obtain the favorable result found in alloy No. I (4A), which had the lowest magnetic properties of any of the casting bronzes tested, the tin content should be kept in the lower part of the 4.0–6.0 per cent range covered by specification B 145, 4A. The tin percentage is in a critical range in the 85:5:5:5 alloy and not all samples meeting the specifications as to tin and zinc contents would be expected to show as favorably as the sample of alloy No. 4A here used. Alloy No. XV (2B) is in the "fair" group in spite of a tin content as high as 7.4 per cent, probably because its zinc and lead contents are low.

Among the casting brasses, alloy No. III (6B) is in a favorable composition range. It has a high zinc content, together with a small amount of tin, and it is entirely in the alpha phase. Alloy No. VIII (6A) is also a single-phase alloy, and while its lower zinc content as compared with 6B would tend to give it higher magnetic properties, this effect should not be great; no adequate explanation is evident as to why this alloy was inferior from the magnetic standpoint to 4A, 5A, and 6B.

Among the wrought brasses, Nos. VI and XI (B 16 and B 21 Grade A) are poor because of zinc contents sufficiently high to result in the presence of some of the beta constituent. This was verified by microscopic examination. No. V (B 36, alloy No. 8) probably also contained beta as cast and as rolled, in which conditions it had even higher magnetic properties than B 16 and B 21 Grade A; but after the solution-quenching treatment this alloy had lower magnetism than the other two and was rated "good."

The unfavorable behavior of alloy No. VII (phosphor bronze) is probably due to iron precipitation associated with appearance of the delta phase. The delta constituent is formed when phosphorus is added to copper-tin alloys with tin present in excess of 4.5 per cent (1). Only small quantities of phosphorus are required to effect the lowering of the solubility of tin in copper. Delta here forms a ternary eutectic with the alpha phase and copper phosphide.

Alloy No. XVI (beryllium copper) was tested at only one iron content, namely, 0.09 per cent. A relatively high iron content, generally 0.15 per cent or more, is inherent in the usual production method for beryllium copper. Specially prepared metal would probably be satisfactory if the iron content were as low as 0.01 or 0.02 per cent. It appears that some iron is precipitated in magnetic form even at 0.09 per cent iron, even though the beryllium is largely retained in supersaturated solid solution after quenching. The precipitation treatment applied to beryllium copper did not cause a further rise in magnetism.

CONCLUSIONS

1. The limits for maximum iron content given in standard specifications for copper alloys are much too high from the standpoint of magnetism if the alloys are to be used for magnetic instrument construction.

2. The suitability of the alloys for magnetic instruments may be evaluated from measurements of their susceptibilities and magnetic moments.

3. These properties are strongly de-

pendent on the amount of iron present as impurity, and their rate of increase with percentage of iron is the most important factor in the evaluation. The relation depends on the form in which the iron is present and is affected greatly by heat-treatment and cold work.

4. For most copper alloys, including the common brasses and bronzes, increase in the magnetic properties with iron content follows a certain pattern or type of curve. The magnetic property increases very slowly at first, then more and more rapidly, and finally rises steeply with increasing iron content. The lower the iron content at which the rate of rise becomes rapid, the less satisfactory is the alloy from the magnetic standpoint.

5. Iron contents falling well within the region of slow rise should be generally suitable for magnetic instruments, those in the middle range are doubtful or perhaps suitable only for instruments of lesser precision, and those in the higher ranges are almost certainly too large for accurate functioning.

6. Three of the alloys tested are inherently high in magnetism and are unsuitable for magnetic instrument construction under any conditions. All of the remaining sixteen alloys are suitable if the amount of iron present in alloyed form is as low as 0.01 per cent.

7. The magnetic properties of most of the copper alloys, both cast and wrought, can be considerably lowered by a solution-quenching treatment. The magnitude of the effect varies with composition, as well as with the iron contents, and whether cast or rolled.

8. The casting alloys having the lowest magnetic properties as cast were found to be 85-5-5-5 (ounce metal, B 145, 4A), valve composition (B 145, 5A), and common yellow brass (B 146, 6A). Other cast alloys were rated good if heat-treated.

9. Without heat-treatment the best of the alloys tested were the wrought alloys binary aluminum bronze (B 169, Alloy C) and nickel silver (B 151, Alloy C). The former is best at the lower iron contents, the latter at higher iron contents. The solution-quenching treatment is very effective in lowering the magnetic properties of aluminum bronze, and also of electrolytic copper, but has little effect on nickel silver. If this treatment is given, electrolytic copper containing low iron impurity is equal to aluminum bronze, and both are better than nickel silver at iron contents as high as 0.50 per cent.

10. Annealing causes the magnetic properties to increase. At very low iron contents the effect is inappreciable, while at high iron contents it may be very great. Nickel silver was the only alloy found that could be safely annealed after rolling when the iron contents were as high as 0.05 per cent.

11. The magnetic properties of the different alloys vary over an extremely wide range with increasing iron contents, and with different thermal and mechanical treatments at the same iron content if the iron is high; but if the iron is low, thermal and mechanical treatments have relatively little effect.

12. The effect of rolling differs in different alloys. For most rolled alloys the rise in magnetic properties begins at lower iron contents and rises more steeply in the rolled than in the cast condition. In some alloys, however, the magnetic properties rise more rapidly in the cast condition than after rolling.

13. The compass needle of a surveying instrument was visibly deflected by placing directly over it specimens having magnetic moments of 4.5×10^{-3} c.g.s. units or higher, or by specimens having susceptibilities of 10×10^{-6} or higher if previously magnetized and 45×10^{-6} or higher if unmagnetized. Deflections of

several degrees occurred at the higher magnetic values.

14. Specimens with unalloyed iron showed magnetism ten to a thousand times as high as specimens containing the same amount of alloyed iron.

15. Low magnetic properties are to be expected only when the alloy, containing a moderate amount of iron impurity, consists of a single phase. Brasses containing the beta constituent with iron as impurity have high magnetic properties, and similarly tin and aluminum beyond the limits of the alpha solid solution cause high magnetism.

Acknowledgments:

The authors wish to acknowledge the assistance of numerous others and to record their appreciation. John H. Frye, Jr., then associated with Lehigh University and now with Bethlehem Steel Co., was Investigator during the first seven months of the project. Dr. Frye's contribution was especially valuable since he took part in organizing the investigation and obtaining the initial results. Yu-lin Yao was Investigator during the last nine months, rendering important aid. Dr. Yao is now in China.

A. L. Jamieson supervised the technical work on behalf of the Frankford Arsenal, and his suggestions and assistance, together with those of E. R. Rechel, were of great value. L. L. Wyman of the War Metallurgy Committee was appointed Research Supervisor for the project. He enlisted an advisory committee which included also J. B. Austin, R. M. Bozorth, E. H. Dix, Jr., J. H. Frye, Jr., M. A. Hunter, H. R. Larsen, A. G. McNish, and V. H. Schnee. Major W. W. Culbertson was Liaison Officer acting under Col. Greenall of the Frankford Arsenal. C. L. Hemmerly gave valuable service as Laboratory Assistant.

In addition to the apparatus loaned by the U. S. Steel Corporation Research Laboratory and the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, a magnetometer was loaned by the W. and L. E. Gurley Co., Troy, N. Y. We regret that space does not permit naming all the companies and individuals who lent cooperation in the way of service or materials.

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DISCUSSION

Mr. J. J. Curran.[1]—The findings of Messrs. Butts and Reiber are very interesting. Particularly interesting is the fact that the common casting alloys (copper-tin-lead-zinc type), I, 85-5-5-5, II, 81-3-7-9, and III, 67-1-3-29, are good from the standpoint of low magnetic susceptibility and magnetic moment, and that in a number of alloys, these properties are reduced still further, for a given iron content, by quenching in cold water from temperatures of 800 C. and higher.

Without attempting to cover the effects of such quenching treatment on other properties of all of the alloys included in the investigation, we wish to point out that alloys of the copper-tin-lead-zinc type, such as 85-5-5-5, 81-3-7-9, and 88-6-2-4, are susceptible to serious deterioration if quenched from 800 C. and higher. Extensive cracking occurs in these alloys in such treatment, not easily visible to the eye, but reflected markedly in their tensile properties and in their pressure-tightness.

However, if tensile strength at 25 per cent or less of specification values, elongation at practically zero, and leakage under pressure can be tolerated in the instruments contemplated in this investigation, the solution treatment will undoubtedly be helpful.

This cracking of the copper-tin-lead-zinc alloys in quenching might easily be due to stress-corrosion cracking, that is, quenching puts the quenched surface in tension, and corrosive action is provided by the molten globules of impure lead.

Mr. G. Sorkin.[2]—I should like to inquire whether the authors have investigated the stability of the alloys with respect to the degree of magnetism which they found.

Mr. G. R. Gohn.[3]—Unpublished data which we obtained during the war in connection with the development of equipment which had to meet the same requirements as the magnetic compasses described by the authors corroborate the results of the authors' studies.

Our tests showed that free-cutting yellow brass rod had distinct magnetic properties which made it unsuitable for use in such equipment. Phosphor bronze containing up to 0.10 per cent of iron, and nickel silver alloys, such as the 18 per cent nickel, 27 per cent zinc alloy, containing even higher percentages of iron were found to be sufficiently nonmagnetic for use in these applications.

Apparently it is not the percentage of iron present so much as the condition in which the iron is present which determines whether or not the non-ferrous material has objectionable magnetic characteristics. In the case of the nickel-silver alloy, the increased solubility of the iron in the nickel undoubtedly led to a somewhat higher tolerance for iron than in the case of the straight copper-zinc brasses.

Mr. G. R. MacDonald.[4]—A phosphor bronze similar to alloy D of A.S.T.M. Specification B 139 - 48 T, with an allowable 1.25 per cent iron maximum has been used in applications that require a non-magnetic material. The alloy is used in rod form, less than 1.25 in. in diameter and with some degree of cold work. With the high iron content, would the magnetic characteristics of the alloy be accentuated by cold rolling subsequent to heat treatment?

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[3] Member of Technical Staff, Bell Telephone Laboratories, Inc., New York, N. Y.

[4] Engineer, Works Laboratory, Apparatus Dept., General Electric Co., Johnson City, N. Y.

MR. CARTER S. COLE.[5]—It is interesting to note that the nickel-silver alloys in the wrought condition give excellent promise for this particular service for which the authors were testing. It should also be noted that, while straight copper showed rapid development of magnetic susceptibility when iron was intentionally added for purposes of test, the amount of iron to be expected in any commercial copper used for wrought products would be less than 0.005 per cent, which would be far under the range where interference from magnetism might be expected. Further information is needed on the properties of leaded and other free-cutting types of copper.

It is clear from Fig. 7 that three of our common cast alloys are suitable after heat treatment for applications where magnetism would be a problem, although Mr. Curran's remarks would indicate that the heat treatment needed to remove the magnetic susceptibility may have adverse effect on strength and porosity for at least some of the alloys. Unanswered questions are why the 4A alloy (85-5-5-5), the 5A alloy (81-3-7-9) and the 6B alloy (commercial yellow brass) show good properties, especially after heat treatment, but the 6A alloy (high-copper yellow brass) which is intermediate in compositon between 5A and 6B showed up so poorly. A simple laboratory test to determine the effectiveness of the heat treatment and lack of damage along the lines indicated by Mr. Curran, both are needed. Perhaps with castings a simple coupon could be devised which would remain attached to the castings during heat treatment and be removed subsequently for test.

A few words of caution regarding the authors' data might also be in order. The data in Tables III and IV for the "as cast" condition of an aluminum bronze alloy is the "as cast" condition of an alloy whose chemical composition is that of the wrought aluminum bronzes, not the chemical composition normally found in cast aluminum bronzes. The maximum iron of the wrought alloy C of A.S.T.M. Specification B 169 is 0.50 per cent, while the minimum iron of alloy 9B of A.S.T.M. Specification B 148 is 0.75 per cent and other cast aluminum bronzes run from 2.5 to 5.0 per cent iron. The same precaution should be used in considering the "as cast" data for alloy XVI in Tables V and VI, as the maximum iron in the wrought alloys in A.S.T.M. Specification B 151 is 0.25 per cent, while the maximum iron permitted in the cast alloys in A.S.T.M. Specification B 149 is 1.5 per cent.

MESSRS. ALLISON BUTTS AND P. L. REIBER, JR. (*authors' closure*).—Mr. Curran has given pertinent information as to deterioration of certain alloys through stress cracking if quenched from 800 C., and the consequent limitation of the solution-quenching treatment for those alloys. It appears likely that the treatment is not necessarily ruled out for the type of service required in instruments, but this question can only be answered by trial application of the treatment to manufactured parts.

Mr. Sorkin's question refers to an important point, an extensive investigation of which was included in the tests. The magnetic properties of many specimens of the alloys were remeasured after various periods, continuing to six months or more. The aging was carried on both at room temperature and at 100 C. with parallel groups of specimens. The remeasurements gave very constant values. No significant changes were found except in cases where the magnetic properties were already too high; even then rather small increases occurred. It might be expected that aging would have greater effect on quenched specimens, but this was not the case. While high iron contents resulted in some instability, it was concluded that the magnetic properties are very stable in all the alloys of suitably low magnetism, and that the effect of aging is of no practical importance whether the material is cast or rolled and whether heat treated or not.

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[5] Assistant Technical Secretary, A.S.T.M. Staff.

We agree with Mr. Gohn that the condition in which the iron is present is the direct determining factor in causing unduly high magnetism, rather than the percentage of iron present. But when the percentage present exceeds the amount which can be held in solid solution, magnetism begins to increase rapidly in accord with the amount of iron precipitated in the ferromagnetic condition.

We assume that Mr. MacDonald uses the term "non-magnetic" in its relative sense as compared with ferrous materials. Phosphor bronze having an iron content approaching 1.25 per cent would not be suitable for precise magnetic instruments. The magnetic properties of the material of this high iron content would in all probability be accentuated by cold work subsequent to heat treatment, and might be raised to a surprising degree.

Mr. Cole's word of caution as to data obtained on cast samples of normally wrought alloys is in order. All the wrought alloys were tested in both cast and rolled conditions for purposes of comparison and study of the effect of cold work.

There are possible explanations for the anomalous behavior of the 6A alloy (test No. VIII) related to its composition, but they cannot be regarded as satisfactory without further tests. The samples as received from the Navy Department were high in iron (0.36 per cent). A new series of samples was made in the laboratory. This series had good magnetic properties at 0.02 per cent iron, but was poor at 0.07 and higher percentages. Where the two series overlapped in iron contents, above 0.36 per cent, the measurements gave high values similar in both series.

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON EVALUATION TESTS FOR STAINLESS STEELS

The Symposium on Evaluation Tests for Stainless Steels was sponsored by Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel, and Related Alloys to provide a review of experience with these evaluation test methods and the relation of results secured with them to the performance of the stainless steels under actual conditions of use. The symposium was presented at the Twelfth and Fifteenth Sessions of the Fifty-second Annual Meeting of the American Society for Testing Materials held in Atlantic City, N. J. on June 30, 1949.

The following papers were presented:

Introductory Summary—F. L. LaQue
Present Knowledge of Low-Carbon 18-8—H. W. Gillett
Corrosion Resistance and Mechanical Properties of Low-Carbon Austenitic Stainless Steels—D. C. Buck, J. J. Heger, F. J. Phillips, and B. R. Queneau
Accelerated Corrosion Testing of Chromium-Nickel Stainless Steel Weldments—F. K. Bloom and M. E. Carruthers
An Appraisal of Methods for Evaluating the Corrosion Resistance of Stainless Steels—M. H. Brown, W. B. DeLong and W. R. Myers
Some Observations on Tests for Intergranular Susceptibility of 18-8 Mo Stainless Steels—Hilmer Ebling and M. A. Scheil
Influence of Carbon and Molybdenum on the Intergranular Corrosion Resistance of Austenitic Chromium-Nickel Steels With and Without Columbium—W. O. Binder and C. M. Brown
Comparative Corrosion Resistance of Stainless Steels in Various Acids—R. B. Mears, C. P. Larrabee, and C. J. Fetner
Comparison of Plant Corrosion Test Results on Austenitic Stainless Steels with Results of Huey and Strauss Tests—H. O. Teeple
Results of Some Plant Corrosion Tests of Welded Stainless Steels—G. F. Comstock
Testing Multiple Specimens of Stainless Steels in a Modified Boiling Nitric Acid Test Apparatus—W. B. De Long

The papers together with discussions are issued as A.S.T.M. Special Technical Publication No. 93, entitled, "Symposium on Evaluation Tests for Stainless Steels."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON RAPID METHODS FOR THE IDENTIFICATION OF METALS

In view of the wide usefulness of rapid methods for the identification of metals a symposium was held to discuss the general principles involved in the various types of methods in current use and also specific applications of rapid identification methods to particular classes of metals and alloys. The symposium was sponsored by Committee E-3 on Chemical Analysis of Metals and presented at Third and Fifth Sessions of the Fifty-second Annual Meeting of the American Society for Testing Materials held in Atlantic City, N. J., on June 28, 1949.

The following papers were presented:

Introductory Remarks—L. A. Wooten
Development, Present State, and Outlook of Spot Test Analysis—Fritz Feigl
Electro Spot Testing and Electrography—H. W. Hermance and H. V. Wadlow
Instruments for Rapid Metal Identification—R. R. Webster
Separating Alloys by Relative Spot Tests—H. Kirtchik
Rapid Methods for the Identification of Copper-Base Alloys—R. P. Nevers
Rapid Identification of Metal Finishes—D. R. Evans and A. Lewis
Examination of Plated and Protective Coatings by Electrographic Analysis—N. Galitzine and S. E. Q. Ashley
Separating Tin-Lead, Antimony-Lead, and Pure Lead by Spot Test Analysis—C. A. Ray
A Field Test Kit for Rapid Identification of Nickel Alloys—H. B. Lea
Rapid Tests for the Identifying Alloy Steels—Elbert C. Kirkham

The papers together with discussions are issued as A.S.T.M. Special Technical Publication No. 98, entitled, "Symposium on Rapid Methods for the Identification of Metals."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON TESTING CAST IRON WITH SR-4 TYPE OF GAGE

The Symposium on Testing Cast Iron with SR-4 Type of Gage was sponsored by Committee A-3 on Cast Iron and presented at the Eighth and Ninth Sessions of the Fifty-second Annual Meeting of the American Society for Testing Materials held in Atlantic City, N. J., on June 29, 1949.

Because cast iron will break with a nonductile fracture under simple tensile stress, its application has occasionally been avoided in favor of more ductile material which will deform and thus sound a warning. Nonductile fractures are known to develop in ductile materials like steel, as in the case of the fatigue failure. Means for exploring stress distribution in castings have been provided by various means and specifically in the strain-resistance wire gage system.

The following fifteen papers were presented:

Stress Analysis of Automotive Cyclinder Blocks—Martin A. Erickson
Residual Stresses in Cylinder Blocks—R. J. King
An Analysis of Locked-In Stresses in Automotive Cylinder Blocks—S. J. Stockett and H. W. Lownie, Jr.
Strain Testing of Crankshafts, Engine Frames and Cylinders—H. M. Hardy and T. O. Kuivinen
Strain Gage Tests on Diesel Cylinder Blocks, Heads, and Pistons—C. L. Newton and J. D. Swannack
Stress-Strain Tests on Rectangular Cast Iron Beams—Oliver Smalley
Stress-Strain Tests on Various Cast Iron Beam Sections—H. M. Hardy and T. O. Kuivinen
Stress Analysis of a Cast Iron 125-lb. Valve Assembly—V. T. Malcolm and S. Low
Stress Analysis of a Cast Iron Split Tapping Sleeve—E. C. Sears, J. W. Miner and E. D. McCauley
Stress-Strain Analysis of Cast Irons for Valve Parts—Harold Wyatt
Residual Stresses in Cast Iron Deaerating Trays—J. A. Cameron
Some Strain Gage Studies of Cast Iron Punch Press Frames—Given A. Brewer
Stress Determination in Cast Irons for Railroad Service—Richard A. Flinn and Robert J. Ely
Location and Measurement of Stresses in Gray Iron Tractor Castings—Hyman Bornstein
Stress-Strain Studies of Cast Iron and Textile Machinery Parts—Victor E. Hillman

The papers together with discussions are issued as A.S.T.M. Special Technical Publication No. 97, entitled, "Symposium on Testing Cast Iron with SR-4 Type of Gage."

SUMMARY OF PROCEEDINGS OF THE SESSION ON RADIOGRAPHY

To provide a review of all of the late developments in the field of radiography, Committee E-7 on Non-Destructive Testing sponsored a session at the Fifty-second Annual Meeting of the American Society for Testing Materials held in Atlantic City, N. J., on June 27, 1949.

The following papers together with discussions are issued as A.S.T.M. Special Technical Publication No. 96, entitled, "Papers on Radiography":

Recent Progress in High Speed Flash Radiography—J. C. Clark
10 Mev X-ray Technique—D. T. O'Connor, E. L. Criscuolo, and A. L. Pace
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THE DIRECT AND CONTINUOUS MEASUREMENT OF BLEEDING IN PORTLAND CEMENT - WATER MIXTURES*

By Rudolph C. Valore, Jr.,[1] James E. Bowling,[1] and R. L. Blaine[1]

Synopsis

An apparatus is described for measuring continuously the water of bleeding as it separates from freshly mixed portland cement-water mixtures. The bleeding water is collected by flotation through carbon tetrachloride. Tests of neat cement pastes at various water-cement ratios by the carbon tetrachloride method and by a float-subsidence method (in which bleeding is identified as the subsidence of the paste surface) yielded bleeding-time curves of similar types, but bleeding rates and capacities calculated from carbon tetrachloride test data averaged about 80 per cent of those obtained from subsidence data. The carbon tetrachloride method was found to give results of satisfactory reproducibility. Experiments for evaluating container boundary friction effects and examples of channeled bleeding have been described. Results of the application of the carbon tetrachloride method to concretes are also presented.

The bleeding of freshly mixed portland-cement pastes, mortars, and concretes may be described as the separation of a portion of the water at the surface of such mixtures. The apparent upward displacement of water in a mix results from the consolidation of the mass of suspended solids due essentially to gravitational forces. High bleeding rates, accompanied by "channeling" and a consequent removal of appreciable quantities of very fine particles from the cement paste matrix to the upper surface of a concrete, may cause planes of weakness in the hardened material. Excessive bleeding may also account for water pockets and loss of bond at the underside of coarse aggregate restricted from movement, as in narrow forms, and at the underside of horizontal reinforcement. A moderate amount of bleeding, however, facilitates finishing operations such as screeding and troweling, and in the fabrication of cement-asbestos products, spun concrete pipe and vacuum concrete, high bleeding cements are desirable.

The accurate measurement of bleeding has long been a problem. Powers,[2] Reed-Lewis,[3] and others have used various means for measuring bleeding and have contributed to our understanding of various phases of the subject. Powers[2] has employed an indirect method in which bleeding is identified as the subsidence of the solid phases in cement-water mixtures. Direct methods, in which the bleeding water was siphoned or otherwise collected, have not generally permitted satisfactory evaluation of bleeding rates and have been unsuitable for testing mixtures of high water-cement ratio for which the surface of demarcation between bleeding water and the original paste is poorly defined. There was the need, therefore, to develop a reproducible direct method for the collection and continuous measurement of bleeding water in mixtures within the range of practicable water-cement ratios.

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[1] Materials Engineer, National Bureau of Standards, Washington, D. C.

[2] T. C. Powers, *Bulletin 2*, Research Laboratory of the Portland Cement Assn. (1939) (includes a bibliography).

[3] E. W. Reed-Lewis, "The Relative Water Capacities of Portland Cements" *Pit and Quarry*, Vol. 31 (August, 1938).

SCOPE

A direct method and apparatus based upon the principle of flotation were devised. This principle required, as a displacement medium, a liquid immiscible with water having a specific gravity intermediate between that of water and that of the cement-water mixture in which bleeding was to be measured, in order to buoy up the bleeding water into a collecting and measuring apparatus. Preliminary experiments resulted in the choice of carbon tetrachloride as a displacement medium[4]. Carbon tetrachloride has a specific gravity of approximately 1.6 at 70 F., is virtually immiscible with water, and is not known to react chemically with the constituents or hydration products of portland cement. When a layer of carbon tetrachloride is placed over the surface of a freshly mixed neat cement paste the bleeding water appearing at the surface moves laterally to a number of collection points. When such a point holds a sufficient amount of water (about 0.05 ml.), the buoyant force is apparently great enough to cause a water globule to break away from the surface and to ascend to the top of the carbon tetrachloride layer.

The apparatus devised permitted the continuous collection and measurement of bleeding water from a selected area of the surface of a sample of neat portland-cement paste, mortar, or concrete.

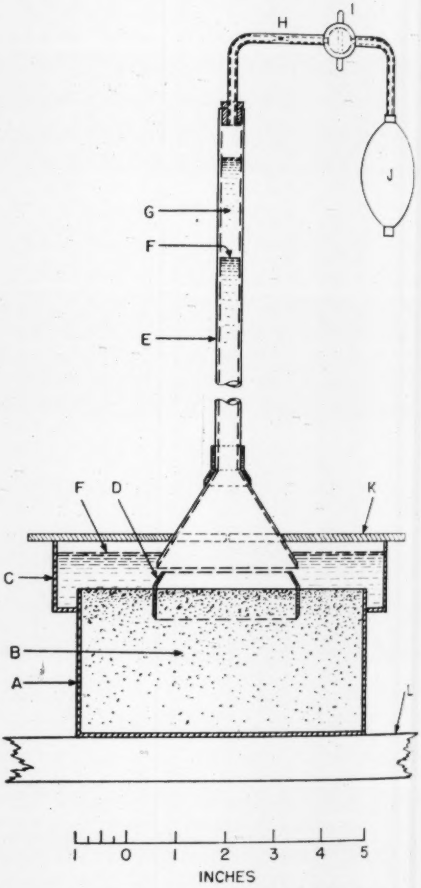

FIG. 1.—Carbon tetrachloride-displacement apparatus for measuring bleeding of neat cement pastes.

A, sample container; *B*, neat cement paste sample; *C*, outer rim; *D*, metal collecting ring; *E*, burette; *F*, carbon tetrachloride levels; *G*, bleeding water; *H*, capillary constriction; *I*, stopcock; *J*, aspirator; *K*, cover; and *L*, sponge rubber base. Burette-funnel assembly remains stationary during test while collecting ring is free to settle with paste surface. Burette holder is not shown.

A series of parallel tests was made by means of this "carbon tetrachloride method" and the previously mentioned subsidence or "float method". One operator made three tests by each method on neat pastes made with each of four portland cements at each of four water-cement ratios.

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[4] See section on Results and Discussion in this paper for the results of the use of other liquids as displacement media.

Tests were made by three operators upon neat pastes made with an additional cement at each of three water-cement ratios, in order to determine the degree of reproducibility among different operators.

Inasmuch as the results obtained with the carbon tetrachloride and float methods were found to differ systematically by more than the amount of the experimental error, additional tests were made. These were directed mainly toward evaluating the boundary friction effect upon bleeding as determined by both methods in tests of neat cement pastes.

Bleeding tests were also made upon concretes prepared with one cement at three water-cement ratios, using the carbon tetrachloride method.

APPARATUS

Carbon Tetrachloride Displacement Apparatus:

A drawing of the carbon tetrachloride displacement apparatus for measuring the bleeding of neat cement pastes is presented in Fig. 1; both the paste sample container and the collecting and measuring apparatus are shown. The container is a brass cup approximately 6 in. in diameter and 3 in. deep. An outer ring 7 in. in diameter is soldered to the perimeter of the cup about 0.5 in. below the top rim of the cup, and extends about 1.5 in. above the rim. Carbon tetrachloride poured into the space between the outer ring and the rim of the cup flows over the surface of the paste sample, which is level with the rim of the cup, without disturbing the paste surface. Bleeding water may be collected from a selected portion of the paste surface by means of the flanged "Dowmetal" collecting ring which floats, partially submerged, in the paste and directs the water through the inverted funnel into the burette. The funnel, burette, and aspirator assembly is held in position by means of a burette holder, not shown in the drawing. Collecting rings approximately 3 in. (7.7 cm.) and 2 in. (4.5 cm.) in diameter, with matching funnel sizes, were employed in conjunction with the 6-in. diameter paste container for the present series of tests.[5]

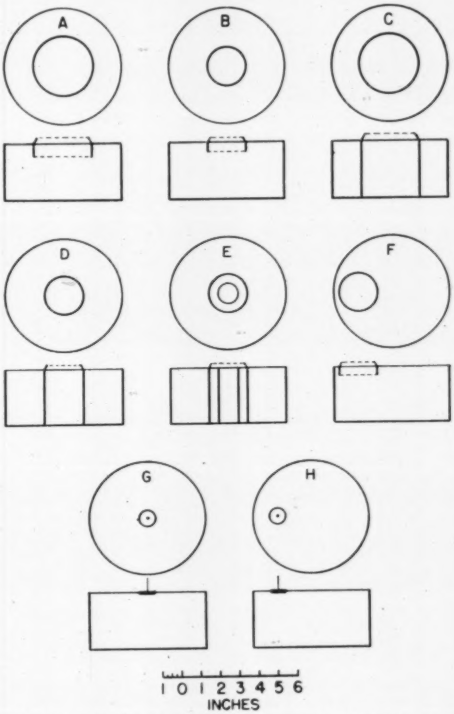

FIG. 2.—Schematic drawing of various test set-ups, showing neat paste sample container and positions of collecting rings and float.

A, normal or center position for 3-in. collecting ring; *B*, normal position for 2-in. ring; *C*, 3-in. collecting ring extending to bottom of container; *D*, 2-in. ring extending to bottom of container; *E*, 2-in. ring and concentrically placed 1-in. tubing extending to bottom of container; *F*, 2-in. ring centered 1.25 in. from container wall; *G*, float in normal position; and *H*, float centered 1.25 in. from container wall.

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[5] Since the completion of these tests the combination of the 2-in. ring and a 4-in. diameter paste container has been found more convenient to use.

For tests of concrete a 4.9-in. (12.5 cm.) diameter collecting ring was used with a container 26.7 cm. deep and 29.2 cm. in diameter. The areas of paste or concrete surface covered by the 3-in., 2-in., and 4.9-in. rings were 47.0, 21.2, and 118.0 sq. cm., respectively. A clear organic plastic cover was placed over the portion of the container surrounding the funnel because of the toxic nature of carbon tetrachloride vapor.[6]

After a paste sample has been placed in the container, and then covered with carbon tetrachloride, the collecting ring is placed in position, normally at the center of the paste surface (*A* and *B*, Fig. 2). The funnel-burette assembly is then lowered to within 0.25 in. of, and directly over, the collecting ring. Carbon tetrachloride is next drawn up into the burette by means of the aspirator to a "zero" burette marking and the stopcock closed. A constricted capillary between the aspirator bulb and the stopcock controls the rate of rise of carbon tetrachloride in the burette. The volume of bleeding water replacing carbon tetrachloride at the top of the liquid column in the burette is then measured periodically during a test.

In tests designed to evaluate the boundary friction or container "edge" effect upon bleeding, modifications in the dimensions or position of the collecting ring were employed. Both types of modifications are shown schematically in *C*, *D*, *E*, and *F* of Fig. 2.

Float-Subsidence Apparatus:

The float or subsidence apparatus used was essentially the same as that described by Steinour,[7] and the normal center and the edge positions of the float are shown schematically in *G* and *H* of Fig. 2. The 6-in. diameter paste container used with the carbon tetrachloride apparatus was also used for determinations of subsidence. The float was a bakelite disk, $\frac{3}{4}$ in. in diameter and $\frac{1}{8}$ in. thick, upon which a needle was mounted vertically. The container was filled with paste, as in the carbon tetrachloride displacement tests, and water was then poured into the outer rim of the container and allowed to flow over the surface of the paste to a depth of about 0.5 in. The float was placed on the surface of the paste (normally the center of the paste surface) and was seated by jarring the container. A cathetometer, graduated in 0.001 cm., was used to determine the relative vertical position of the point of the needle periodically during the test.

The float method was used only in tests of neat cement pastes in the present investigation.

MATERIALS

Eight brands of portland cements were used. Chemical analyses, Wagner turbidimeter and Blaine air-permeability specific surface values, and the percentage air content of standard 1:4 mortars for these cements are presented in Table I. The cements met all of the physical requirements of Federal Specification SS-C-192, Non-air-entraining, type I,[8] except that three of the cements exceeded the requirement for the maximum percentage by volume air entrainment, as indicated in Table I.

Potomac River sand and $\frac{3}{4}$-in. maximum size coarse aggregate were used in the concretes. A sieve analysis of the combined fine and coarse aggregates is given in Table II.

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[6] See section on Results and Discussion in this paper for precautions that should be observed in the handling of carbon tetrachloride and other liquids used as displacement media.

[7] Harold H. Steinour, *Bulletin 4*, Research Laboratory of the Portland Cement Assn. (1945).

[8] Federal Specification SS-C-192, Type Ia, for Cements, Portland, May 20, 1946.

Sample Preparation and Testing Procedures

All mixing and testing were done in a laboratory maintained at 70 ± 2 F. The relative humidity was maintained at 50 ± 5 per cent for tests of neat cement pastes but was uncontrolled for tests of concretes.

TABLE I.—CHEMICAL ANALYSES, SPECIFIC SURFACE, AND MORTAR AIR CONTENT OF CEMENTS USED IN BLEEDING TESTS.

Cement	Chemical Analyses, per cent								Calculated Potential Compound, per cent			Specific Surface, sq. cm. per g.		Mortar Air Content, per cent
	CaO	MgO	Al_2O_3	Fe_2O_3	SiO_2	SO_3	Insoluble Residue	Ignition Loss	C_3A	C_3S	C_2S	Wagner Turbidimeter	Air Permeability	
A	64.0	2.6	6.4	2.9	21.0	1.5	0.1	1.0	12	49	23	1780	3390	8.5[a]
B	62.6	3.1	6.2	3.0	21.7	1.9	0.1	0.8	11	38	33	1710	3060	6.6
C	63.0	2.8	6.0	2.8	21.6	1.7	0.1	1.4	11	43	29	1710	3240	9.2[a]
D	63.2	2.6	6.3	3.0	21.1	1.8	0.3	0.7	12	45	27	1920	3380	6.6
E	65.1	0.9	4.8	5.4	21.5	1.5	0.1	0.5	4	57	18	1850	2950	4.3
F	63.4	2.3	6.0	2.4	21.5	1.9	0.3	0.9	12	45	28	1760	3080	6.3
G	62.6	3.5	5.6	2.7	21.9	1.9	0.2	0.9	10	41	32	1750	3160	11.5[a]
H	64.2	3.6	6.4	2.6	20.2	1.7	0.1	1.2	13	56	16	1570	2985	8.0

[a] Failed to meet requirement of Federal Specification SS-C-192, Non-air-entraining, type I, by exceeding the maximum permissible percentage air content, by volume.

TABLE II.—SIEVE ANALYSIS OF COMBINED AGGREGATES USED IN CONCRETES (40 PER CENT SAND, 60 PER CENT COARSE AGGREGATE).

Sieve size	Percentage Retained
¾ in.	0
⅜ in.	40.4
No. 4	21.0
No. 8	7.4
No. 16	7.2
No. 30	9.0
No 50	9.7
No. 100	4.0
Pan	1.3
Total	100.0

Neat Portland-Cement Pastes:

Neat pastes with water-cement weight ratios 0.32, 0.40, 0.55, and 0.70 were tested. In each case sufficient material was mixed to provide about 1600 cu. cm. of paste. The capacity of the previously described paste container was approximately 1300 cu. cm. The pastes were hand-mixed in a hemispherical bowl in a steady and vigorous manner. The total mixing time was 6 min., which was divided into two 3-min. mixing periods separated by a 3-min. interval during which the paste was quiescent. It was found necessary to use this relatively lengthy interrupted mixing procedure in order to lessen the effect of "false set" tendencies observed for shorter, continous mixing schedules.

The paste was carefully poured into the container immediately following the second mixing period, and the completion of pouring coincided with the starting time for each test. The preliminary operations outlined above in the description of apparatus required 2 to 4 min., and the first observation was made 4 or 6 min. after the starting time. Additional observations were made at 2-min. intervals until 30 min. after the starting time and at 10-min. intervals thereafter until the cessation of bleeding. It was found that an inappreciable amount of bleeding occurred after the first 100 min. of a test.

The schedule for mixing and making observations was the same for all tests, whether made by the carbon tetrachloride or float method.

Two measures of bleeding were calculated from the observed readings: the initial rate of bleeding and the bleeding capacity. Typical curves obtained from test data are shown in Fig. 3 in which cubic centimeters of bleeding water per square centimeter of paste surface, or centimeter of subsidence, are plotted *versus* time.

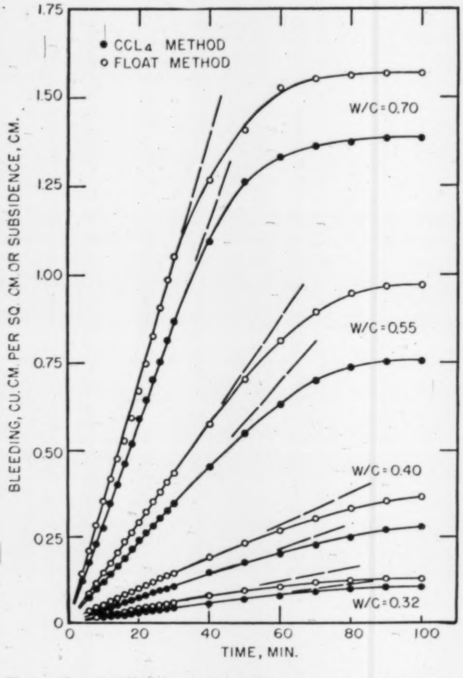

FIG. 3.—Individual bleeding and subsidence curves for neat pastes made with cement C at various water-cement ratios.

The differences shown are typical of the differences in magnitude of results obtained by the two test methods. The burette readings for the carbon tetrachloride method were divided by the area of the collecting ring before being plotted.

Both bleeding and subsidence were found to occur at an approximately constant rate during the first portion of each test, which confirms the results reported by Powers.[2] The initial rate was simply the slope of the straight line passing through the plotted points observed during the initial 30-min. period. The slopes were calculated by the method of least squares. For convenience the calculated initial rate of bleeding is expressed in millionths of cu. cm. per sq. cm. of paste surface per second for both the carbon tetrachloride and the float methods. The values obtained by both methods are expressed in comparable units. The values plotted in Fig. 3 for the carbon tetrachloride method, in cu. cm. per sq. cm., were obtained by dividing the burette readings actually observed by the area of the collecting ring, so that the bleeding curves obtained by both the carbon tetrachloride and the float methods might be plotted to the same scale of ordinates.

The "bleeding capacity" is defined as the fraction of the initial volume of a paste that separated as bleeding water during the entire course of a test. For the carbon tetrachloride method the bleeding capacity was calculated as the ratio of the final burette reading (total volume of bleeding water) to the initial volume of the cylinder of paste directly below the collecting ring. The value for the bleeding capacity calculated from the subsidence data was simply the ratio of the total subsidence of the float to the initial height of the paste. (This is the same as the $\Delta H'$ of Powers[2]). It is easily seen that values for bleeding capacity, expressed in cu. cm. per cu. cm. of paste for the carbon tetrachloride method, and in cm. per cm. for the float method, are numerically equivalent. For convenience, the bleeding capacity is expressed in cu. cm. per cu. cm. for both methods.

It was necessary to apply a correction to the observed total subsidence since the observations did not include the subsidence which occurred during the first 4 or 6 min. after the start of a test. This correction was readily made by assuming that subsidence during the initial period prior to the first observation occurred at the previously discussed constant rate. No similar correction was made for bleeding data obtained by the carbon tetrachloride method in tests of neat pastes.

Concretes:

Bleeding tests of concretes were made by the carbon tetrachloride method only. The concrete mixes were designed for net water-cement weight ratios of 0.40, 0.55, and 0.70. The cement factors were adjusted to give a slump of 6 ± 1 in., and the volume-ratio of sand to total aggregate was maintained at 0.40. Each aggregate batch was wholly immersed in water in an individual container for 24 hr., after which water in excess of the quantity to be used in the mix was removed. The mixing was done in a rotating tilted-drum mixer of 2 cu. ft. capacity, and sufficient materials were used to yield 1 cu. ft. of concrete. The interrupted mixing schedule for the neat pastes was also followed in mixing the concrete batches. Slumps were determined for each batch by one operator, and a second operator began the fabrication of the test sample immediately following the mixing period. The concrete was placed in the container in three layers, and each layer was rodded 25 times with a $\frac{5}{8}$-in. diameter bullet-nose rod. The top surface of the final layer was made level by screeding.

Bleeding rates were determined in the same way as for the neat pastes, using the appropriate constants based upon the larger dimensions of the sample container and the collecting ring. In cases where the bleeding curve departed from

TABLE III.—INITIAL RATES OF BLEEDING AND BLEEDING CAPACITIES FOR NEAT PASTES MADE WITH EIGHT BRANDS OF PORTLAND CEMENT, AS DETERMINED BY THE CARBON TETRACHLORIDE AND FLOAT SUBSIDENCE METHODS.

The "normal" center position for the collecting ring and float were employed. The three-inch collecting ring was used for all carbon tetrachloride tests except those made upon cements F, G, and H, for which the 2-in. collecting ring was used. Each value is a mean for three individual determinations.

Cement	Water-Cement Weight Ratio	Initial Rate of Bleeding, millionths of cu. cm. per sq. cm. per sec.			Bleeding Capacity, cu. cm. per cu. cm.			Coefficient of Variation, per cent			
								Initial rate		Capacity	
		CCl_4 Method	Float Method	Ratio: $\frac{CCl_4}{Float}$	CCl_4 Method	Float Method	Ratio: $\frac{CCl_4}{Float}$	CCl_4	Float	CCl_4	Float
A	0.32	22	25	0.88	0.007	0.012	0.58	0.1	5.0	8.2	9.8
	0.40	55	67	0.82	0.024	0.032	0.75	0.4	2.4	1.8	7.3
	0.55	151	212	0.71	0.072	0.087	0.83	3.8	4.1	4.3	3.2
	0.70	296	395	0.75	0.151	0.132	1.14	1.4	3.3	1.4	2.5
B	0.32	30	42	0.71	0.018	0.023	0.78	4.1	7.2	2.7	5.6
	0.40	72	91	0.79	0.044	0.050	0.88	2.0	4.7	2.2	11.7
	0.55	214	268	0.80	0.116	0.142	0.82	3.7	4.0	1.5	2.5
	0.70	518	593	0.87	0.210	0.222	0.95	2.1	2.6	5.4	2.4
C	0.32	26	34	0.76	0.014	0.018	0.78	2.2	3.8	5.8	7.7
	0.40	60	78	0.77	0.036	0.047	0.77	2.4	2.1	2.3	3.9
	0.55	201	244	0.82	0.098	0.131	0.75	2.3	4.0	2.9	4.3
	0.70	500	520	0.96	0.173	0.201	0.86	0.5	6.3	1.4	3.0
D	0.32	19	26	0.73	0.009	0.014	0.64	2.6	5.0	5.0	9.6
	0.40	53	62	0.85	0.028	0.036	0.78	1.9	1.8	1.7	2.2
	0.55	142	177	0.80	0.083	0.094	0.88	1.1	5.9	1.0	1.2
	0.70	389	405	0.96	0.161	0.192	0.84	0.8	4.4	1.1	3.1
Mean, cements A through D				0.81			0.81	2.0	4.2	3.1	4.9
E	0.40	81	...	....	0.043	....	....	1.4	...	1.3	...
	0.55	226	...	....	0.107	....	....	1.7	...	4.5	...
	0.70	512	...	....	0.178	....	....	2.5	...	0.1	...
F	0.55	179	214	0.84	0.084	0.081	1.04	2.3	3.6	3.9	1.4
G	0.55	187	236	0.79	0.089	0.116	0.77	2.9	4.9	2.4	1.1
H	0.40	77	...	....	0.042	....	....	0.5	...	2.4	...
	0.55	232	...	....	0.116	....	....	4.7	...	0.7	...

TABLE IV.—INITIAL RATES OF BLEEDING AND BLEEDING CAPACITIES FOR NEAT PASTES MADE WITH CEMENT E, AS DETERMINED BY DIFFERENT OPERATORS USING THE CARBON TETRACHLORIDE METHOD.

A 3-in. collecting ring in the "normal" center position was used.

Water-Cement Weight Ratio	Operator	Initial Rate of Bleeding, 3 Tests						Bleeding Capacity, 3 Tests					
		1	2	3	Mean	Coefficient of Variation, per cent		1	2	3	Mean	Coefficient of Variation, per cent	
		millionths of cu.cm. per sq. cm. per sec.				Each Operator	For Means, Among Operators	cu. cm. per cu. cm.				Each Operator	For Means, Among Operators
0.40	X.......	80	80	82	81	1.4		0.043	0.044	0.043	0.043	1.3	
	Y.......	76	86	80	81	5.2		0.038	0.037	0.037	0.038	1.6	
	Z.......	86	82	81	83	2.5		0.037	0.042	0.042	0.040	10.0	
Mean..............................					82		1.3				0.040		5.9
0.55	X.......	224	222	231	226	1.7		0.104	0.103	0.114	0.107	4.5	
	Y.......	219	229	228	225	1.9		0.101	0.103	0.101	0.102	0.8	
	Z.......	244	237	239	240	0.7		0.134	0.123	0.116	0.124	5.8	
Mean..............................					230		3.0				0.111		8.6
0.70	X.......	495	526	515	512	2.5		0.178	0.177	0.178	0.178	0.1	
	Y.......	498	488	493	493	0.9		0.172	0.198	0.185	0.185	5.8	
	Z.......	516	507	497	510	2.3		0.184	0.184	0.178	0.182	1.6	
Mean..............................					505		1.6				0.182		1.6
Mean for 3 water-cement ratios..............						2.1	2.0					3.5	5.4

TABLE V.—INITIAL RATES OF BLEEDING AND BLEEDING CAPACITIES FOR NEAT PASTES MADE WITH EIGHT BRANDS OF PORTLAND CEMENT AS AFFECTED BY (1) THE EFFECTIVE DIAMETER OF THE PASTE CONTAINER (CARBON TETRACHLORIDE METHOD ONLY) AND (2) THE POSITION OF THE COLLECTING RING OR FLOAT ON THE PASTE SURFACE.

Each value shown is a mean for two or three individual determinations.

Cement	Water-Cement Weight Ratio	Test Method	Size of Collecting Ring, in.	Initial Rate of Bleeding, millionths of cu.cm. per sq. cm. per sec.				Bleeding Capacity, cu. cm. per cu. cm.			
Effective Container Diameter, in............				6	3	2	1	6	3	2	1
A..........	0.40	CCl_4	3	55	54	...	...	0.024	0.023	...	...
B..........	0.40	CCl_4	3	72	70	...	...	0.044	0.038	...	...
C..........	0.40	CCl_4	3	60	56	...	...	0.036	0.032	...	...
D..........	0.40	CCl_4	3	53	50	...	...	0.028	0.025	...	...
F..........	0.55	CCl_4	2	179	..	179	173	0.084	...	0.081	0.073
Position on Paste Surface of Collecting Ring or Float				Center		Edge		Center		Edge	
G..........	0.55	CCl_4	2	187		193		0.089		0.089	
G..........	0.55	Float	..	236		205		0.116		0.103	
H..........	0.40	CCl_4	2	77		77		0.042		0.042	
H..........	0.55	CCl_4	2	232		261[a]		0.116		0.124	

[a] Pronounced channeling was observed. The value given is a weighted mean of the "normal" rate, 0.000230 cu. cm. per sq. cm. per sec. observed during the first 10 to 18 min. (3 tests), and an increased rate due to channeling, 0.000283 cu. cm. per sq. cm. per sec., observed during the remainder of the initial 30 minute period during which the rate is normally computed. See Fig. 9 for bleeding curve.

a straight line before the end of the initial 30-min. period, the calculation of the rate was based only upon the linear portion of the curve. In calculating bleeding capacities, a correction was applied similar to that used in the calculations of subsidence data for neat pastes. The necessity for the correction apparently resulted from the removal of some of the bleeding water by the screeding operation.

Results and Discussion

Neat Portland Cement Pastes:

The results obtained in bleeding and subsidence tests of neat pastes made with eight brands of portland cement are presented in Table III. The "normal" position of the collecting ring or float, at the center of the paste surface, was employed. Each value presented for the initial rate of bleeding and the bleeding capacity is the mean for a set of three determinations. Tests of pastes made with cements A through D at water-cement weight ratios of 0.32, 0.40, 0.55, and 0.70 form a series of parallel tests performed for the purpose of comparing the carbon tetrachloride and float methods. The results shown for cements E through H were obtained during the course of tests made for the purpose of evaluating the container edge effect and the degree of reproducibility achieved by different operators. These test results are presented in Tables IV and V. All results shown in Tables III and V were obtained by one operator.

Reproducibility of Results.—Values presented in Table III, for the initial rate of bleeding and bleeding capacity for cements A through D, show a systematic lack of agreement between the carbon tetrachloride and float test results. For both rates and capacities the mean CCl_4-float ratio was 0.81, indicating that the values obtained by the carbon tetrachloride method averaged about one fifth less than those obtained by the float method. Figure 3 shows individual bleeding and subsidence curves for pastes of various water-cement ratios made with cement C. The differences shown between curves for each water-cement ratio paste are representative of the differences in magnitude of results obtained by the two test methods. It is significant, however, that no difference may be discerned in the type of curves obtained. The individual initial rate values calculated from carbon tetrachloride test data were lower than those calculated from subsidence data for every paste tested, but there was generally better agreement between the two methods for the 0.70 water-cement ratio pastes than for the other pastes. Values for bleeding capacity calculated from carbon tetrachloride test data were likewise smaller than those obtained from subsidence data, except for cement A at 0.70 water-cement ratio and cement F at 0.55 water-cement ratio.

The degrees of reproducibility obtained in evaluating bleeding characteristics by both methods are indicated by the coefficients of variation[9] presented in Table III. Each mean coefficient shown for cements A through D represents 16 groups of three samples, or 48 individual tests. Comparison of the mean coefficients indicates a somewhat higher degree of reproducibility for the carbon tetrachloride than for the float method, for both the initial rate of bleeding and the bleeding capacity. The initial rates were more reproducible than the capacities for both methods.

Values for the coefficients of variation of the results of carbon tetrachloride tests of pastes made with cement E by three operators are shown in Table IV, and agree quite well with those shown in Table III for other cements tested by

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[9] The standard deviation divided by the arithmetic mean and multiplied by 100 is the coefficient of variation expressed in per cent.

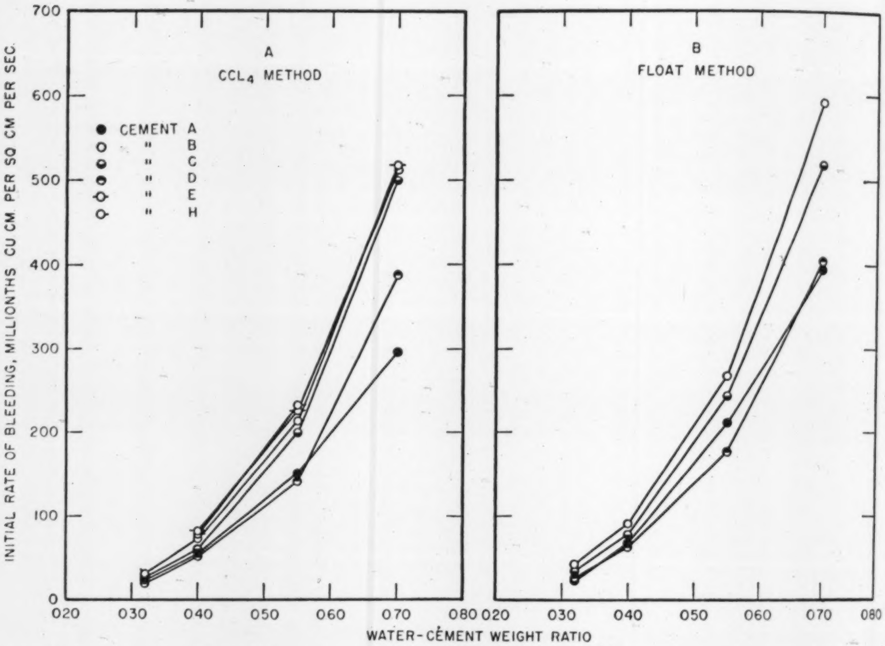

FIG. 4—Initial rate of bleeding *versus* water cement ratio for neat cement pastes tested by two methods.

Each plotted point represents a mean for three determinations.

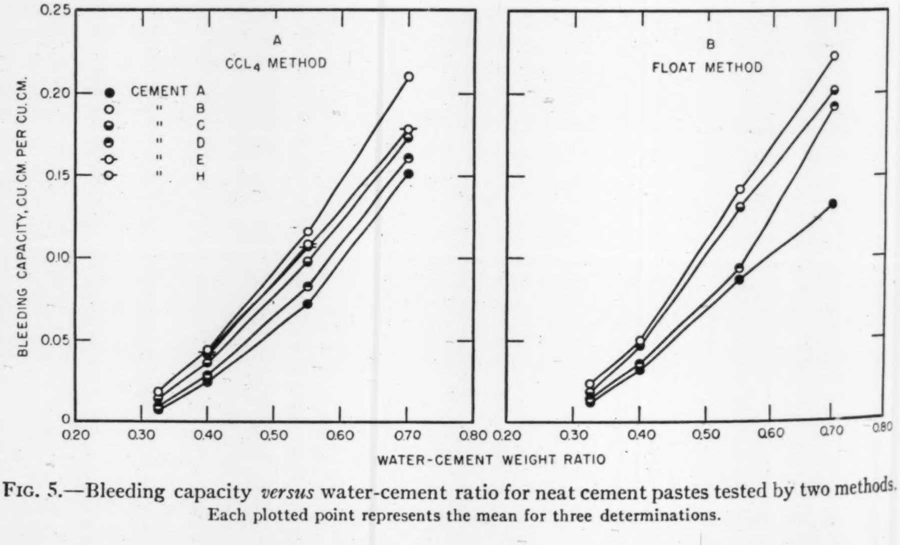

FIG. 5.—Bleeding capacity *versus* water-cement ratio for neat cement pastes tested by two methods.

Each plotted point represents the mean for three determinations.

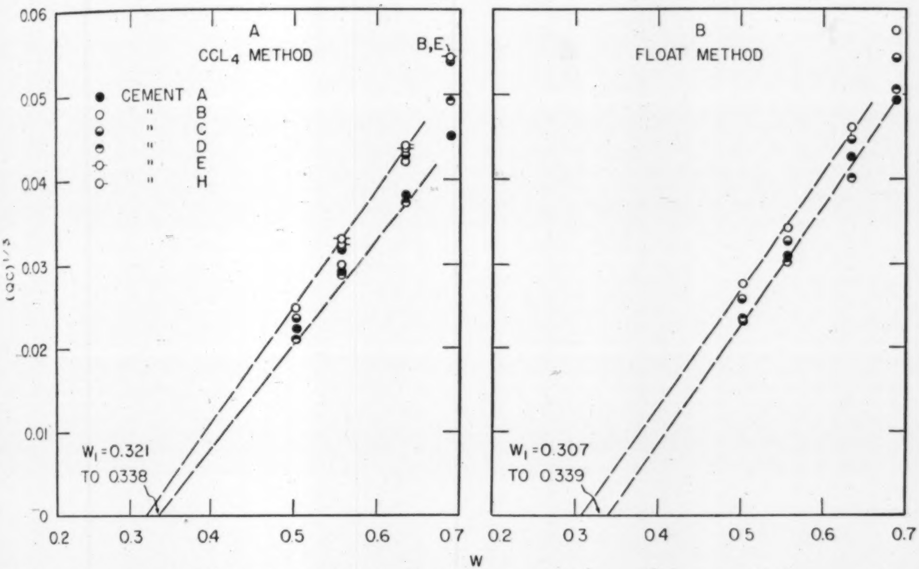

FIG. 6.—Application of the Powers bleeding rate equation, $(Qc)^{\frac{1}{3}} = K^{\frac{1}{3}} (w - w_i)$, in determining w_i, the immobile water factor for neat cement pastes.

Q is the initial rate of bleeding; K is a constant for a given cement; and c is the volume of cement, w the volume of water, and w_i the volume of immobile water, all in a unit volume of paste. If the equation is applicable a plot of $(Qc)^{\frac{1}{3}}$ *versus* w should yield a straight line with an intercept on the w axis at $w = w_i$ and a slope of $K^{\frac{1}{3}}$. Each plotted point represents the mean for three determinations.

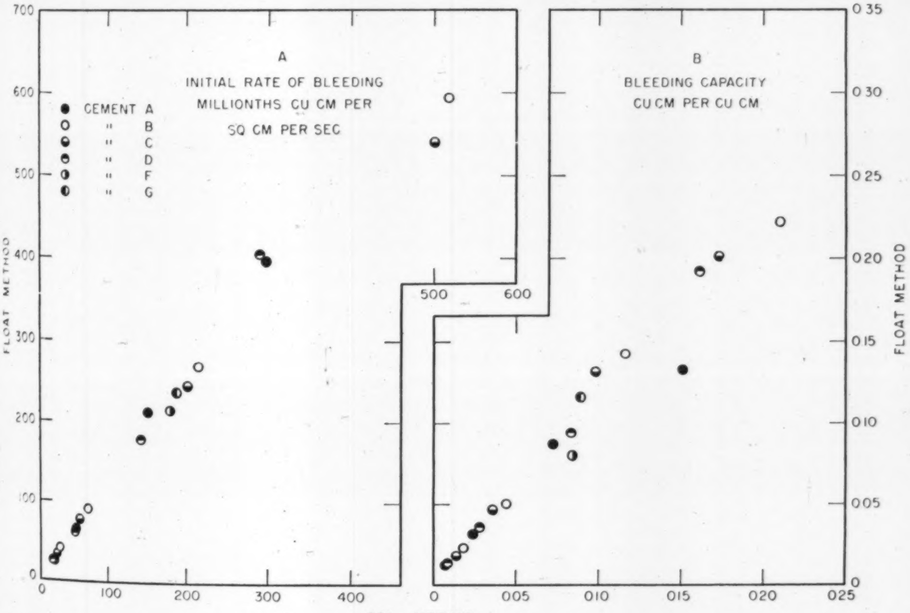

FIG. 7.—Values for *A*, the initial rate of bleeding and *B*, the bleeding capacity obtained by the carbon tetrachloride method *versus* corresponding values obtained by the float method for neat cement pastes.

Each plotted point represents means of three values obtained by each method.

the same method. The mean value for nine groups of three samples, or 27 individual tests, was 2.1 per cent for the initial rates, compared with 2.0 per cent in Table III. Corresponding mean values for the bleeding capacity were 3.5 per cent in Table IV and 3.1 per cent in Table III.

Coefficients of variation for the mean values obtained by three operators for each water-cement ratio, which serve as indications of the relative reproducibility among operators, are also presented in Table IV. Mean values for the rate of bleeding determined by the three operators showed as good agreement as individual values determined by a single operator. Mean values for bleeding capacity determined by three operators did not agree as well as corresponding values for the initial rate. Operators Y and Z had no previous experience with the method used, in contrast to operator X who made all of the determinations reported in Tables III and V.

Different Ways of Representing Bleeding Data.—The relationships between the initial rate of bleeding and water-cement ratio are shown in Fig. 4 for both the carbon tetrachloride and float methods. The relationships between bleeding capacity and water-cement ratio are similarly shown in Fig. 5. Figure 6 shows the application of the equation derived by Powers[2] for the initial rate of bleeding to the results of the present tests. In one form of the equation, $(Qc)^{\frac{1}{3}} = K^{\frac{1}{3}}(w - w_i)$, in which Q is the initial rate of bleeding, K is a constant for a given cement (depending upon specific surface and other factors), and c is the volume of cement, w the volume of water, and w_i the volume of immobile water,[10] all in a

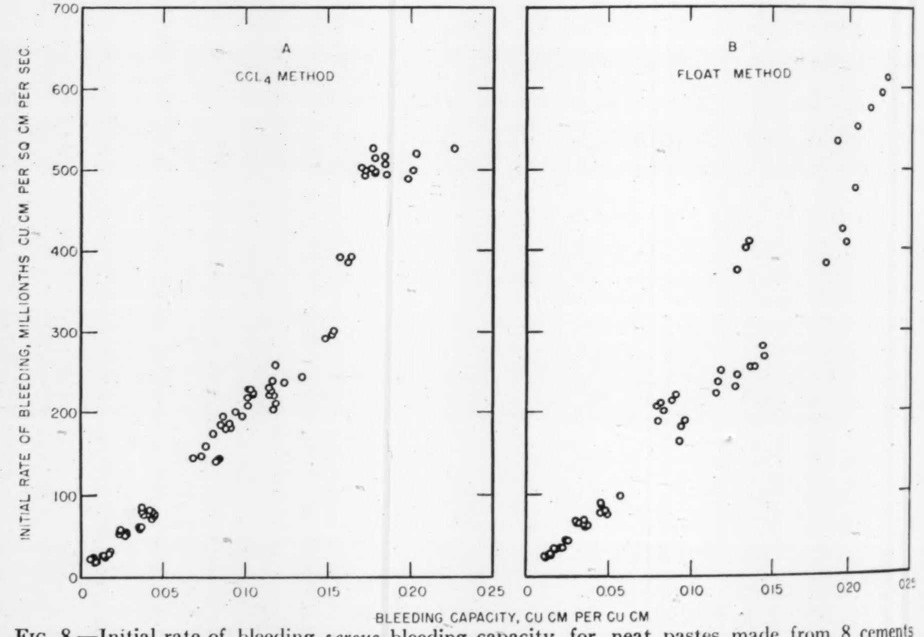

FIG. 8.—Initial rate of bleeding *versus* bleeding capacity for neat pastes made from 8 cements with water-cement weight ratios of 0.32 to 0.70, and tested by two methods. Each plotted point represents an individual determination.

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[10] This immobile water is the water that is held stationary with respect to the solid particles, and hence, does not participate in the bleeding. For a more complete discussion see Powers (footnote 2).

unit volume of paste. When this equation is valid a plot of $(Qc)^{\frac{1}{3}}$ against w for a given cement should yield a straight line having an intercept on the w axis at $w = w_i$ and a slope of $K^{\frac{1}{3}}$. No weight was given to points for the 0.70 water-cement ratio (w = approximately 0.69) in drawing the best-fitting straight lines in Fig. 6, since "channeled" bleeding, as distinguished from normal bleeding, usually occurred for this water-cement ratio. Values for the immobile water factor, w_i, indicated in Fig. 6, of 0.32 to 0.34, were obtained for the carbon tetrachloride test results, and 0.31 to 0.34 for the float method. Each point plotted represents an average for three tests.

Figure 7 indicates the degree of correlation between the two test methods for initial rates and bleeding capacities. The correlation appears to be linear for the initial rates, and virtually linear for the capacities.

The relationships between initial rates of bleeding and bleeding capacities, for both the carbon tetrachloride and the float methods are shown in Fig. 8. This figure appears to confirm the findings of Powers[2] that there is a good linear correlation between the two measures of bleeding, that is, between rates and capacities, for rates up to 300 millionths cu. cm. per sq. cm. per sec. and capacities up to 0.15 cu. cm. per cu. cm. Each point plotted in Fig. 8 represents results for a single sample of paste.

The Boundary Friction Effect.—Results and relationships for neat cement pastes, as obtained by the carbon tetrachloride and float methods, and presented in Table III and Figs. 4 through 8, show a general similarity, but also show an unexplained difference in magnitude of approximately 20 per cent. A brief study of the effect of container edge upon bleeding characteristics was made in an effort to throw some light on possible reasons for this difference. Tests of two types were made.

In the first type of test, used for the carbon tetrachloride method only, the diameter of the paste container was effectively reduced by artificially "adding" edge. This was done by using collecting rings which extended to the bottom of the container, as shown schematically in *C* and *D* of Fig. 2. The effective diameter of the container for this condition was equal to the diameter of the collecting ring. Still more edge was added, as shown in *E* of Fig. 2, by placing a 3-in. length of 1-in. tubing upright upon the bottom of the container in a position concentric with the 2-in. ring and the container walls. The ratio of edge to paste surface was the same, in this case, as when the container diameter was 1 in.

In the second type of experiment, both the carbon tetrachloride and float methods were used, and bleeding and subsidence were determined for the center and a point near the edge of the paste container, as shown schematically in *F* and *G* of Fig. 2.

The results for both types of tests are shown in Table V. Each value given is the mean for two or three determinations. Pastes with water-cement ratios of 0.40 and 0.55 were tested; most tests were made for the relatively low 0.40 water-cement ratio which was expected to exhibit more pronounced boundary friction effects than the higher water-cement ratio pastes. Reducing the effective diameter of the paste container from 6 to 3 in., for the pastes made with cements A through D, caused an average reduction in initial rate of bleeding of 5 per cent and an average reduction in bleeding capacity of 10 per cent. Reducing the effective diameter of the container from 6 to 2 in. for the 0.55 water-cement ratio paste made with cement F did not change the initial rate of bleeding but caused a reduction in bleeding capacity of 4 per cent. Reducing the effective diameter to 1 in. caused a reduction in initial rate of 3 per cent and a reduction in capacity of 13 per cent for this paste.

In the small group of tests of the second type for pastes made with cements G and H, there was no reduction in bleeding rate calculated from carbon tetrachloride test data when the position of the collecting ring was changed from the center of the paste surface to a point near the edge of the container. Instead, there was a somewhat higher rate near the edge than at the center, except for the 0.40 water-cement ratio paste made with cement H, which gave the same rate for both positions of the collecting ring. Tests of the 0.55 water-cement ratio paste made with cement G by the float method indicated a rate of subsidence near the edge of the container appreciably smaller than at the center, thus confirming results which were described by Powers.[2] It is possible that some lateral re-orientation occurs during the settlement of the particles and is responsible for the nature of the results observed. Data of the type shown in Table V may explain only part of the difference between results obtained by the carbon tetrachloride and float methods.

Channeled Bleeding.—Channeled bleeding is distinguished from normal bleeding by the rupture of the paste structure by vertical channels ending at the paste surface in easily visible "craters." For a given cement there appears to be a limiting water-cement ratio above which normal bleeding is supplemented by channeled bleeding. The velocity of flow through the channels is such that appreciable quantities of fine particles are carried in suspension by the bleeding water and are deposited at the channel openings. The result is a surface layer of a very high water-cement ratio paste which constitutes a definite plane of weakness in the hardened material.

In the present tests, the surface of a paste exhibiting pronounced channeling usually showed a concentration of paste mounds resulting from channel openings near the container walls. A portion of a bleeding curve, showing the effect of channeling in causing an increased rate of bleeding after initial normal bleeding, is shown in Fig. 9. It was obtained in a test of 0.55 water-cement ratio paste made with cement H, using the carbon tetrachloride method with the collecting ring near the container wall. The 0.70 water-cement ratio pastes made with cements B, C, D, and E exhibited channeling, but the effects for the center position of the collecting ring were not pronounced.

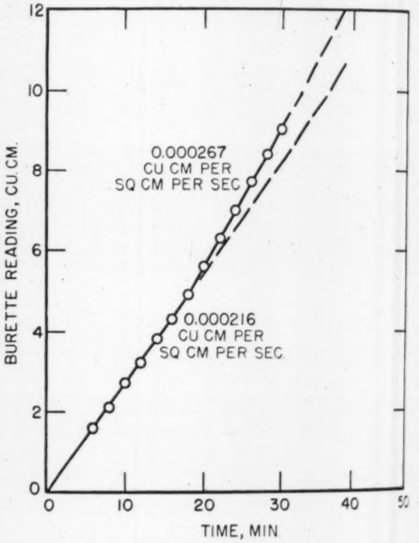

FIG. 9.—Individual bleeding curve (incomplete) for a neat cement paste showing the effects of channeling.

The sample was made with cement H at 0.55 water-cement weight ratio and tested by the carbon tetrachloride method with the 2-in. collecting ring centered 1.25 in. from the container wall. Note an increase of approximately 25 per cent in the rate of bleeding after 18 min. at the initial rate.

Since large quantities of concrete as normally used are made with water-cement ratios sufficient to produce channeling, it appears that this phenomenon poses an important problem for the concrete technologist.

The Use of Liquids Other Than Carbon Tetrachloride as Displacement Media.—Although the results obtained in the use of carbon tetrachloride as the displacement medium were satisfactory, it was considered desirable to explore the use of other liquids. Results of the use of some of these liquids are given in Table VI. These results were obtained in tests of a 0.60 water-cement ratio neat paste, using a container 4 in. in diameter and 3 in. deep, in combination with the 2-in. collecting ring. The tests were performed at 77 ± 3 F. In these tests the numerical values for bleeding rates and capacities did not appear to vary systematically with the liquid used as displacement medium. It is probable that many other liquids would likewise give adequate results. It should be noted that by using mixtures of various liquids a medium of any specific gravity within the desired range may be obtained. It was also found that a wetting agent dissolved in the displacement medium reduced the average size of the bleeding water globule that separates from the surface of a paste (Table VI). In the present type of test it is desirable that the volume of the globule not exceed the resolution of reading of the burette (0.05 to 0.10 cu. cm. in this case).

TABLE VI.—RESULTS OF THE USE OF CARBON TETRACHLORIDE AND OTHER LIQUIDS AS DISPLACEMENT MEDIA IN BLEEDING TESTS OF A NEAT CEMENT PASTE (WATER-CEMENT WEIGHT RATIO = 0.60).

Displacement Medium	Specific Gravity (at 77 F.)	Approximate Volume of Water Globule, cu. cm.	Initial Rate of Bleeding, millionths cu. cm. per sq. cm. per cm.	Bleeding Capacity, cu. cm. per cu. cm.
Carbon tetrachloride	1.59	0.05	243 236	0.098 0.101
x-dibromoethylbenzene[a]	1.74	0.10	222 235	0.106 0.107
x-dibromoethylbenzene-benzene mixture	1.47	0.15	246 237	0.097 0.104
x-dibromoethylbenzene-kerosene mixture	1.45	0.15	232	0.099
x-dibromoethylbenzene-kerosene mixture with wetting agent added[b]	1.45	0.003 to 0.005	237 240	0.105 0.098
Tetrachloroethylene	1.62	0.10	240 232	0.101 0.096
Mean for 11 tests with various liquids			236	0.101
Coefficient of variation, per cent			2.6	4.3

[a] Sold under name "Alkazene 42" by Dow Chemical Co.

[b] "Aerosol O.T.," made by American Cynamid and Chemical Corp.

All the liquids listed in Table VI are of a toxic nature, and most of the other liquids that may be used are probably toxic also. Because it is more volatile than the other liquids used, carbon tetrachloride is the least satisfactory in this respect and requires the greatest precautions in handling. The following is a list of precautions which may be profitably applied to any of these or other toxic liquids:

1. Exercise care in pouring the liquid over the cement-water mixture so as to not spill the liquid or breathe its vapor.
2. When the test has been started, the exposed portion of the liquid surface surrounding the funnel should be kept covered for the duration of the test.
3. Place a drain cock at the bottom of the space between the outer ring and the sample container in order to drain the liquid into a separatory funnel at the completion of a test. The liquid may then be separated from the bleeding water and used again.
4. Do not use toxic liquids in confined or poorly ventilated spaces. The test should be performed under a hood if adequate temperature control can be maintained. Both carbon tetrachloride and tetrachloroethylene are inexpensive and generally available. It is reported that

experience in the dry cleaning industry points to tetrachloroethylene as the less hazardous with respect to toxicity.[11]

Application of the Carbon Tetrachloride Displacement Method to Concretes:

The results of a series of carbon tetrachloride bleeding tests of concretes made with cement E at 0.40, 0.55, and 0.70 water-cement weight ratios, are presented in Table VII. Average values for bleeding data for corresponding neat pastes made with cement E, which appear in Tables III and IV, are also shown.

TABLE VII.—BLEEDING DATA FOR CONCRETES MADE WITH CEMENT E COMPARED WITH DATA FOR NEAT PASTES MADE WITH THE SAME CEMENT AT CORRESPONDING WATER-CEMENT RATIOS.[a]

Cement Factor, bags per cu. yd.	Water-Cement Ratio, by weight	Test Number	Volume of Paste in Unit Volume of Concrete[b]	Slump, in.	Initial Rate of Bleeding, millionths of cu. cm. per sq. cm. per sec.			Bleeding Capacity, cu. cm. per cu. cm.			Ratio: Bleeding per Unit volume Paste in Concrete to Bleeding of Neat Paste	
					Concrete	Per Unit Volume paste in Concrete[b]	Neat Paste	Concrete	Per Unit Volume Paste in Concrete[b]	Neat Paste	Initial Rate	Capacity
8.9	0.40	1	0.355	7.0	28	79		0.0046	0.0130			
		2		7.0	24	68		0.0040	0.0113			
		3		6.0	28	79		0.0050	0.0141			
		4		7.0	24	68		0.0049	0.0138			
Mean					26	74	81	0.0046	0.0130	0.043	0.87	0.30
Coefficient of variation, per cent					7.7			8.5				
6.0	0.55	1	0.288	6.0	68	236		0.0073	0.0254			
		2		6.0	68	236		0.0070	0.0243			
		3		5.5	61	212		0.0065	0.0226			
		4		5.0	72	250		0.0061	0.0212			
Mean					67	234	226	0.0067	0.0234	0.107	1.04	0.22
Coefficient of variation, per cent					6.0			6.9				
4.6	0.70	1	0.259	5.5	182	705		0.0078	0.0300			
		2		6.5	166	640		0.0095	0.0366			
		3		6.0	201	775		0.0100	0.0386			
		4		6.5	201	775		0.0111	0.0429			
Mean					188	725	512	0.0096	0.0370	0.178	1.42	0.21
Coefficient of variation, per cent					7.8			12.4				

[a] Bleeding data for neat pastes are mean values for three determinations obtained by Operator X, as shown in Tables III and IV.

[b] Bleeding data for a unit volume of paste in the concrete were computed by dividing each value obtained for concrete by the volume of paste in a unit volume of concrete.

The values in column 4 of Table VII indicate the volume of paste in a unit volume of concrete and were calculated by using the value 3.15 for the specific gravity of the cement. The values in columns 7 and 10 for the initial rate and bleeding capacity for a unit volume of paste in the concrete were calculated by dividing the values given in columns 6 and 9 by the appropriate values in column 4. The ratios given in the last two columns were calculated by dividing the bleeding value expressed in terms of the paste content of the concrete (columns 7 and 10) by the corresponding values for the neat pastes (columns 8 and 11). If concrete is considered as a neat cement paste with aggregate added, the ratios in columns 12 and 13 indicate the effect of the "additions" of aggregate upon the bleeding characteristics of the neat pastes.[12] Thus, for the 0.55 water-cement ratio, the initial rate of bleeding of the paste in the 6 bags per cu. yd. concrete was virtually the same as that for the corresponding neat paste. For the leaner mix, the aggregate appeared to produce more rapid bleeding: the ratio 1.42 indicates that the 0.70 water-cement ratio paste in concrete had an initial rate of bleeding 42 per cent higher than that of the neat paste of the same water-cement ratio.

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[11] G. P. Fulton, National Institute of Cleaners and Dyers, Silver Spring, Md. (private communication, 1949).

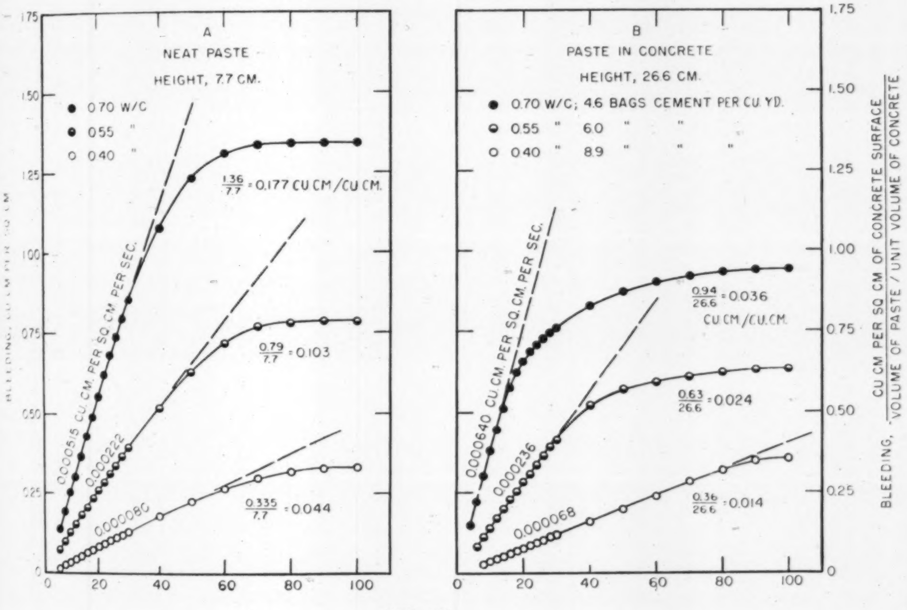

FIG. 10.—Individual bleeding curves for *A*, neat cement pastes, and *B*, cement pastes in concretes of the same water-cement ratios and made with the same cement (E).

The curves for pastes in concretes were obtained by dividing the values for bleeding per sq. cm. of concrete surface by the volume of paste per unit volume of concrete. Values calculated for initial rates of bleeding and bleeding capacites are shown. The expedient of representing the bleeding of the paste only in a concrete in this manner was designed to show over-all effects of aggregate, and does not take into account the effects of aggregate in increasing the forces causing and resisting bleeding.

It is seen that the bleeding capacity of the pastes in the concretes were only 21 to 30 per cent as much as the capacities for the corresponding neat pastes.

Individual bleeding curves for neat pastes and concretes made with cement E are shown in Fig. 10. The data for pastes are expressed as cu. cm. per sq. cm. of paste surface. In order to show the bleeding data for the paste constituent in the concretes, the data for concretes are expressed in cu. cm. per sq. cm. of concrete surface, divided by the volume of paste per unit volume of concrete (Table VII, column 4). Thus, the slopes of the initial portions of the bleeding curves (the initial rates of bleeding) as plotted are comparable for both neat pastes and concretes. The final or 100-min. ordinates do not show comparative bleeding capacities as plotted because of the difference in depth of the sample containers used in tests of pastes and concretes. The bleeding capacity may be calculated in each case by dividing the 100-min. ordinate by the appropriate container depth (7.7 cm. for the paste container and 26.7 cm. for the concrete container). The similarity between the two 0.40 water-cement ratio curves is a coincidence resulting from the choice of these particular container depths.

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[12] Dividing the initial rate of bleeding of a concrete by the volume of paste in a unit volume of concrete is an expedient employed here for comparative purposes only. The use of this expedient is based upon the assumption that the paste constituent comprises a fraction of a plane section through any portion of a concrete equal to the volume of paste in a unit volume of concrete. No attempt has been made to analyze further the bleeding of concretes in terms of the effect of the weight of aggregate in increasing the forces causing bleeding, and the opposite effect of the decrease in capillary radii in increasing the forces resisting bleeding, as discussed by Powers (footnote 2).

The effect of the addition of aggregate to a neat cement paste (in which sense concrete is considered here) is to increase or decrease the initial rate of bleeding of the paste, depending upon the proportion of aggregate added. The effect of such an addition upon the bleeding capacity is a highly arrestive one, causing relatively large decreases in bleeding capacity. The arrestive effect, which has been attributed to interference among aggregate particles as the mass of solids consolidates, may only appear to inhibit bleeding. If bleeding water collects at various points within the concrete, the physical properties of the hardened material may be adversely affected. Therefore, a bleeding test upon concrete may not give a complete picture. More satisfactory data would be obtained in tests not only of the concrete itself but also of the corresponding neat paste.

Any satisfactory bleeding test for concretes is more difficult to perform than an equally satisfactory test for neat pastes, and, therefore, a high degree of reproducibility should not be expected. Concretes require a much larger sample, and differences in moisture conditions and gradation of aggregates may produce wide variations in test results.

SUMMARY AND CONCLUSIONS

A simple apparatus has been devised which permits the collection and continuous measurement of the bleeding water in portland cement water mixtures by displacement of the bleeding water by carbon tetrachloride.

Tests of neat cement pastes with water-cement weight ratios 0.32 to 0.70 by the carbon tetrachloride method and by observing the subsidence of a float placed upon the paste surface produced bleeding curves of similar types.

Both the initial rate of bleeding and the bleeding capacity evaluated from carbon tetrachloride test data averaged about 20 per cent lower than corresponding values calculated from subsidence data.

The reproducibility of the carbon tetrachloride method is indicated by an average coefficient of variation of about 2 per cent for bleeding rates and somewhat above 3 per cent for bleeding capacities. Results obtained by different operators agreed virtually as well as those obtained by a single operator in repeated tests.

Experiments designed to evaluate the container boundary friction effect upon bleeding indicated that bleeding and subsidence were not identical at all points over the surface of neat pastes, but did not fully explain the difference in the magnitude of results obtained by the carbon tetrachloride and float test methods. Further work on boundary friction effects appears desirable.

The carbon tetrachloride method was applied successfully to concretes. The bleeding capacity of the paste constituent of concrete was found to be much smaller than the capacity of a neat paste of the same water-cement ratio. It appears, therefore, that a test of concrete alone may give inadequate and misleading data.

Although tests of mortars were not made, the carbon tetrachloride method should be easily applicable to such mixtures.

It is believed that the opportunity afforded by this method to examine visually the bleeding water with reference to the concentration of suspended solids constitutes an advantage in evaluating the effects of bleeding.

LONG-TIME TESTS OF CONCRETE CONTAINING CEMENTS OF TYPES I, II, AND III UNDER VARIOUS STORAGE CONDITIONS*

By W. J. McCoy[1] and S. B. Helms[1]

Synopsis

This paper contains compressive strength data of ¾-in. gravel concrete up to 16 yr. for twelve cements each of types I, II, and III under three different storage conditions, namely, inside storage, outside storage, and 70 F. fog-room storage. The chemical analysis, potential compound composition and A.S.T.M. specification test data is tabulated for each cement. These tabulations permit the A.S.T.M. mortar strengths and other characteristics of these cements to be compared with the long-time concrete strengths. One interesting feature of the paper is the test data which show the performance of type III cements over a period of 16 yr. under various storage conditions.

There has been relatively very little comparative long-time concrete test data published for type I, II, and III cements, especially where the physical and chemical properties of the cements have been determined and the concrete specimens have been fabricated under closely controlled conditions.

M. O. Withey[2] has published various articles on long-time tests of concrete conducted under his supervision at the University of Wisconsin. These reports deal chiefly with type I cement. An article on strengths of type III concretes up to 10 yr. was published in 1942 by Louis Schuman.[3] His studies were comprehensive but the paper did not include comparative tests with other types of cement. Comparative concrete test data for the various types of cement have become available to us at our research laboratory and it was our thought that in view of the dearth of such information in the literature it might serve as a basis for a paper.

In 1931 when high-early-strength cement had begun to come into use and the A.S.T.M. had just published tentative specifications covering this type of cement, a program of long-time tests of concrete containing the normal or regular (type I) portland cement of that time and this new type cement known as high-early-strength (type III) was started at our research laboratory. Later on in 1937 cements known then as dark or moderate heat and now as type II were included in the test program. This program is now rather extensive with various new type cements being added from time to time, but for the sake of simplification and in order to have long-time test data available, this paper will cover only twelve cements each of types I, II, and III. These selected cements include products of other producers as well as some Lehigh cements.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] Director of Research and Research Engineer, respectively, Lehigh Portland Cement Co., Coplay, Pa.

[2] M. O. Withey, *The Wisconsin Engineer*, February, 1915, February, 1918, November, 1920, February, 1936; *Journal*, Am. Concrete Inst., February, 1931; Withey and Wendt, *Journal*, Am. Concrete Inst., February, 1943.

[3] Louis Shuman, "Ten-Year Tests of High-Early-Strength Cement Concretes," *Journal of Research*, Nat. Bureau Standards, Vol. 29, No. 6, December, 1942, p. 397. (*RP* 1508.)

TABLE I.—PROPERTIES OF TYPE I CEMENTS.[a]

Chemical Test Results, per cent

Sample	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	Loss	Total	Free CaO	Insol.	C_3S	C_2S	C_3A	C_4AF
No. 1	18.80	3.65	5.91	63.55	3.64	1.65	2.20	99.40	3.63	0.31	66	4	9.5	11.1
No. 2	20.50	2.39	5.47	64.65	3.88	1.70	0.87	99.46	2.40	0.20	62	11	10.5	7.3
No. 3	20.48	2.80	6.52	63.35	3.16	1.49	1.07	98.87	1.86	0.21	50	21	12.5	8.5
No. 4	21.44	2.81	6.25	63.50	3.13	1.52	0.69	99.34	1.33	0.09	45	28	11.8	8.6
No. 5	20.62	2.74	6.62	64.40	2.19	1.76	0.99	99.32	1.95	0.10	52	20	12.9	8.3
No. 6	21.14	3.31	6.13	63.70	3.12	1.39	0.74	99.53	0.80	0.21	49	24	10.7	10.0
No. 7	20.76	2.72	6.48	62.73	2.07	1.77	2.96	99.49	1.30	0.18	45	26	12.6	8.3
No. 8	22.12	2.54	6.76	61.76	3.10	1.69	1.07	99.04	0.56	0.14	29	41	13.6	7.7
No. 9	21.66	2.34	5.86	63.89	3.17	1.59	0.92	99.43	0.74	0.11	48	26	11.6	7.1
No. 10	22.44	3.07	4.53	63.17	3.43	1.76	1.06	99.40	0.94	0.29	47	29	6.8	9.3
No. 11	21.37	2.16	6.05	62.73	3.49	1.60	1.71	99.11	1.28	0.17	45	28	12.4	6.6
No. 12	21.33	2.15	6.16	62.94	3.64	1.78	0.88	98.88	0.86	0.16	45	28	12.7	6.5

Physical Test Results

Sample	Tensile Strength, psi.				Passing No. 200 Sieve, per cent	Autoclave Expansion, per cent	N.C.	Time of Set, Gillmore Needle, min.: sec.	
	1 day	3 day	7 day	28 day				I.S.	F.S.
No. 1	133	235	293	338	90.7	disintegrated[b]	23.5	4:15	7:10
No. 2	127	213	312	383	89.4	disintegrated[b]	23.0	4:05	6:50
No. 3	102	233	283	432	96.5	0.35	25.0	4:45	7:25
No. 4	92	193	285	378	90.8	0.27	23.5	4:50	7:50
No. 5	110	250	332	443	94.0	5.50[b]	24.0	4:35	7:30
No. 6	83	188	285	405	86.9	0.12	21.5	4:10	6:55
No. 7	172	270	340	455	90.5	0.10	23.0	2:20	4:40
No. 8	63	185	255	405	92.0	0.17	24.0	3:10	6:10
No. 9	137	238	328	443	95.7	0.10	23.5	4:20	6:50
No. 10	182	252	327	440	97.2	0.20	25.0	4:10	6:40
No. 11	128	252	313	428	91.3	0.21	24.0	4:30	6:45
No. 12	147	280	344	442	91.0	0.24	24.0	4:20	7:15

[a] In this table the following abbreviations are used: N.C. = Normal consistency. I.S. = Initial set. F.S. = Final set.

[b] Sound by steamed pat test.

TABLE II.—PROPERTIES OF TYPE II CEMENTS.[a]

Chemical Test Results, per cent

Sample	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	Loss	Total	Free CaO	Insol.	C_3S	C_2S	C_3A	C_4AF
No. 25	20.84	5.06	6.30	61.06	2.85	1.79	1.14	99.04	0.44	0.11	36	33	8.1	15.4
No. 26	21.50	4.02	5.58	62.82	3.04	1.71	0.75	99.42	0.28	0.09	44	29	8.0	12.2
No. 27	22.16	4.22	5.18	62.85	2.97	1.62	0.57	99.57	0.27	0.12	42	32	6.6	13.3
No. 28	21.56	4.31	5.07	62.81	2.83	1.68	1.28	99.54	0.62	0.12	47	27	6.2	15.4
No. 29	21.70	4.09	5.11	62.35	4.10	1.54	0.64	99.53	0.22	0.05	45	28	6.6	12.4
No. 30	21.80	4.33	5.07	62.51	3.48	1.53	0.65	99.37	0.15	0.07	44	29	6.1	13.2
No. 31	21.48	4.65	5.63	62.33	2.87	1.61	0.48	99.05	0.20	0.10	41	30	7.1	14.1
No. 32	24.56	3.26	4.00	63.40	1.78	1.66	0.63	99.29	0.20	0.11	35	44	5.1	9.9
No. 33	21.14	4 31	5.47	61.94	4.17	1.67	0.73	99.43	0.27	0.06	44	28	7.2	13.1
No. 34	22.60	4.37	5.29	63.00	1.76	1.54	0.58	99.14	0.38	0.09	39	36	6.6	13.4
No 35	22.52	4.02	4.66	63.70	1.76	1.79	0.72	99.17	0.23	0.23	46	30	5.6	12.2
No. 36	23.64	3.18	4.22	64.72	1.67	1.45	0.73	99.61	0.14	0.13	47	33	5.8	9.7

Physical Test Results

Sample	Tensile Strength, psi.				Compressive Strength, psi.				Passing No. 325 Sieve, per cent	Wagner S.S.	Autoclave Expansion, per cent	N.C.	Time of Set, Gillmore Needle, min.: sec.	
	1 day	3 day	7 day	28 day	1 day	3 day	7 day	28 day					I.S.	F.S.
No. 25	132	233	295	425	403	887	1830	3920	88.8	1890	0.041	22.5	3:00	5:15
No. 26	127	253	390	513	475	1430	2380	4580	93.0	1900	0.075	23.5	3:00	5:30
No. 27	120	263	343	500	394	1170	2170	4940	90.7	1870	0.052	24.0	4:00	6:00
No. 28	135	305	372	515	590	1660	2520	5070	93.8	1810	0.070	24.0	3:30	5:45
No. 29	133	288	357	510	394	1120	2170	4940	92.2	1920	0.085	23.5	2:30	5:00
No. 30	130	275	367	498	407	1140	2020	4420	92.7	1820	0.072	24.0	2:30	4:45
No. 31	92	267	358	475	322	947	2080	4630	94.0	1890	0.072	24.0	3:15	5:15
No. 32	105	245	293	460	358	1040	1450	2280	92.1	1840	0.093	23.5	4:30	6:30
No. 33	127	288	350	485	450	1140	2150	4550	95.5	1880	0.093	24.5	2:15	4:30
No. 34	115	253	353	465	380	1243	2260	4770	96.5	1930	0.024	24.0	2:45	4:30
No. 35	175	342	395	497	603	1620	2280	4180	97.2	1880	0.010	28.0	3:00	5:00
No. 36	128	278	382	495	430	1270	1860	3670	90.3	1605	0.004	22.5	4:15	6:15

[a] In this table the following abbreviations are used:
S.S. = Specific Surface. I.S. = Initial Set.
N.C. = Normal Consistency. F.S. = Final Set.

TABLE III.—PROPERTIES OF TYPE III CEMENTS.[a]

CHEMICAL TEST RESULTS, PER CENT

Sample	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	Loss	Total	Free CaO	Insol.	C_3S	C_2S	C_3A	C_4AF
No. 13	18.24	2.88	6.78	64.33	3.24	2.31	1.33	99.11	2.11	0.13	67	2	13.1	8.8
No. 14	19.60	2.30	5.44	65.39	2.23	2.42	1.32	98.70	2.78	0.61	71	3	10.5	7.0
No. 15	18.84	2.77	7.09	61.68	3.05	2.69	2.35	98.47	1.64	0.46	49	17	14.1	8.4
No. 16	18.86	2.73	7.21	62.30	3.12	2.45	2.21	98.88	2.10	0.37	51	16	14.5	8.3
No. 17	18.64	2.78	7.14	62.16	3.07	2.77	2.20	98.76	2.21	0.66	52	15	14.2	8.5
No. 18	18.26	2.66	7.32	62.19	2.92	2.54	3.13	99.02	1.93	0.40	54	12	14.9	8.1
No. 19	19.16	2.29	6.43	64.00	3.30	2.45	1.74	99.37	1.08	0.14	62	9	13.2	7.0
No. 20	19.92	2.64	6.60	62.59	2.64	2.45	2.53	99.37	1.37	0.12	48	21	13.0	8.0
No. 21	19.14	2.48	6.72	62.09	3.40	2.50	2.90	99.23	0.95	0.90	52	16	13.6	7.6
No. 22	20.30	3.61	6.09	62.20	1.72	2.47	2.92	99.31	0.86	0.26	46	24	10.0	11.0
No. 23	19.20	2.15	5.85	65.01	2.24	2.32	2.24	99.01	2.39	0.57	70	2	11.9	6.6
No. 24	19.58	3.05	7.05	63.60	1.98	2.28	2.29	99.83	0.98	0.09	52	17	13.5	9.3

PHYSICAL TEST RESULTS

Sample	Tensile Strength, psi.				Passing No. 200 Sieve, per cent	Autocalve Expansion, per cent	N.C.	Time of Set, Gillmore Needle, min.: sec.	
	1 day	3 day	7 day	28 day				I.S.	F.S.
No. 13	258	395	432	460	99.1	0.17	25.0	4:10	7:00
No. 14	277	363	415	425	97.2	0.13	25.0	4:25	7:25
No. 15	295	388	405	477	98.1	0.35	24.0	3:45	5:45
No. 16	232	350	405	465	96.8	0.44	25.0	4:45	7:15
No. 17	283	370	435	462	96.5	0.48	24.0	2:35	4:15
No. 18	283	368	482	515	96.9	0.19	23.0	3:25	6:00
No. 19	278	413	450	520	98.9	0.08	24.0	3:25	7:00
No. 20	250	357	432	540	94.7	0.03	24.0	3:25	6:10
No. 21	263	412	455	415	98.3	0.03	24.0	3:00	5:55
No. 22	240	367	440	505	98.0	0.04	25.0	3:50	8:05
No. 23	292	387	465	475	96.9	0.04	25.0	3:40	5:55
No. 24	255	353	453	475	96.4	0.06	24.0	3:30	5:55

[a] In this table the following abbreviations are used:
N.C. = Normal Consistency.
F.S. = Final Set.
I.S. = Initial Set.

The physical and chemical properties of these 36 cements are given in Tables I, II, and III. It should be pointed out that the potential composition is calculated from the chemical analysis according to the formulas given in A.S.T.M. Specification C 150 – 47.[4]

It will be noted that Tables I and III do not contain test data for compressive strength of mortar or Wagner specific surface because the concrete cylinders were made prior to the inclusion of these methods in the A.S.T.M. specifications for the respective type I and type III cements.

TEST METHODS

The concrete specimens were made with the same proportions, materials and fabrication procedure in so far as feasible. The general provisions of A.S.T.M. Standard Method C 39 – 27[5] were followed making 3 by 6-in. cylinders for the test program. Fixed quantities of Delaware River sand (passing the No. 4 sieve) and $\frac{3}{4}$-in. to No. 4 Delaware River gravel were hand mixed into concretes containing approximately 6.25 bags of cement per cu. yd., each mix was adjusted to a 70 per cent flow (equivalent to about 6-in. slump). The size gradation of the sand and coarse aggregate was closely controlled by sieving and recombining various fractions.

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[4] Standard Specifications for Portland Cement (C 150-47), 1947 Supplement to Book of A.S.T.M. Standards, Part II, p. 1.

[5] Standard Methods of Making Compression Tests of Concrete (C 39-27), 1927 Book of A.S.T.M. Standards, Part II, p. 112.

The net water-cement ratio for the concrete specimens fabricated in 1930–1931 and containing types I and III cements varied slightly according to consistency requirements but approximated 0.87 on a volume basis which is equivalent to about 6.5 gal. per sack. The concrete specimens containing type II cements that were started in 1937–1938 were made up with these same mix proportions and contained 6.25 bags of cement per cu. yd., but a fixed water-cement volume ratio of 0.80, or 6 gal. per sack, was employed. On the average this represents a departure of less than 0.5 gal. per sack from the test series on types I and III cements.

For ages of less than 28 days all specimens were moist cured; these specimens in groups of three were obtained from different batches made on different days. Actually more data were recorded up to 28 days than shown in the tables, but these were omitted because of their non-essential character. The long-time test cylinders were reserved in groups of three for each age and test condition so that one in each group had been hand mixed by each of three different operators, usually on different days. For each cement a total of 72 specimens were subdivided for continual fog curing, and for both indoor and outdoor storage after a 7-day curing period. The inside storage on concrete shelves in the laboratory was under general conditions of low humidity, particularly in wintertime, while the specimens stored outside were placed on steel gratings on a flat roof exposed to the weather. Thus the latter 3 by 6-in. cylinders are estimated to have been subjected to at least 50 cycles of natural freezing and thawing each year. Concrete compressive strength tests are reported for 1, 7, and 28 days with standard curing and at age 3 months, 1, 2, 4, 8, 12, and 16 yr. under the described conditions of storage. In the case of the type II cements only 8-yr. test results are available for this report, the specimens having been prepared in 1937 and 1938.

In 1935 it became apparent that variations in the moisture content of the cylinder specimens at the time of test would be reflected in comparisons of test results at different ages. In consideration of this uncertainty it was decided that specimens other than those in moist storage should be soaked in water 24 hr. before testing. Notations have been made in the tables to show when these changed test conditions apply. The change in method was believed to be justified because it brought about a more reproducible state of saturation independent of weather conditions. It will be noted in the tabulated results that a wetter condition of test often is a possible explanation of an apparent lowering of strength in successive tests.

TEST RESULTS

The compressive strengths of the concretes made from the various cements have been listed in Tables IV, V, and VI for types I, III, and II cements, respectively. In practically all cases each value is the average for three test specimens. A detailed examination of 126 complete sets of compressive strength data for two cements of each type showed an average maximum deviation of 4.41 per cent. The maximum deviation exceeded 10 per cent in only 4 per cent of the 126 sets examined and in no case exceeded 12 per cent.

The main significance of these data is to indicate concrete strength characteristics for these three types of cement when stored under the given

TABLE IV.—TYPE I CEMENT CONCRETE.
Compressive concrete strengths of 3 by 6-in. cylinders, psi.

DAMP ROOM STORAGE

Cement	1 day	7 day	28 day	3 month	1 yr.	2 yr.	4 yr.	8 yr.	12 yr.	16 yr.
No. 1	555	2540	4370	5340[b]	5390	5220	6040	5560	5880	6370
No. 2	545	2650	4870	5200	5860	5870	6110	6150	7060	7050
No. 3	354	2800	4810	6000	6120	5760	6000	6210	6820	6840
No. 4	239	2010	4350	5350	5750	5460	5680	6120	6240	6130
No. 5	320	2550	4840	5340	5360	5610	6220	5890	6330	6380
No. 6	218	1660	3940	5260	5720	5910	5650	5430	5900	5690
No. 7	582	3020	5070	5790	5770	6370	6830	6870	7000	6710
No. 8	232	1920	4710	5960	5860	6360	6760	7150	6620	6700
No. 9	598	2780	4900	5360	6040	6620	6550	7290	7270	7410
No. 10	745	3040	5130	5710	6790	6990	6900	6810	7290	7620
No. 11	509	2930	5150	5150	6000	6290	6590	6100	7030	6840
No. 12	569	2610	4240	5100	5660	5870	5950	6390	7000	6820
Average	450	2540	4700	5460	5860	6030	6270	6330	6700	6710

INDOOR STORAGE (LABORATORY AIR) AFTER 7-DAYS CURING

Cement	3 month	1 yr.	2 yr.	4 yr.	8 yr.	12 yr.	16 yr.
No. 1	3740[b]	4060	4170	4840	5030	4880[a]	5180
No. 2	3680	4090	4200	4950	5340	5040[a]	5440
No. 3	3220	3610	3920	4310	5150	4970[a]	5380
No. 4	2660	3040	3310	3530	4150	3760[a]	4030
No. 5	3650	3840	4230	4980	5550	4760[a]	5560
No. 6	2500	2690	2980	3080	3770	3210[a]	3430
No. 7	4260	3860	4450	4400[a]	5050	5470	5400
No. 8	3030	3140	3450	3200[a]	3880	4620	4920
No. 9	3460	3700	4100	3820[a]	4890	5370	5300
No. 10	3660	4520	4780	4210[a]	5260	5510	5600
No. 11	3730	4190	4600	4170[a]	4760	5310	5630
No. 12	3180	3500	3880	3930[a]	4640	4630	4870
Average	3400	3690	4010	4120	4790	4800	5060

OUTDOOR STORAGE (NATURAL WEATHERING) AFTER 7-DAYS CURING

Cement	3 month	1 yr.	2 yr.	4 yr.	8 yr.	12 yr.	16 yr.
No. 1	4860[b]	5660	5140	6020	5130	5180[a]	5060
No. 2	4740	5820	5350	5480	4980	5130[a]	5420
No. 3	4030	4570	5540	5550	5320	5540[a]	5560
No. 4	3090	4590	4650	4780	4880	5210[a]	5190
No. 5	4300	5120	5410	5100	4390	4840[a]	4230
No. 6	3650	4520	5110	5430	4380	4460[a]	4750
No. 7	4580	5170	5900	5260[a]	5160	5910	5620
No. 8	4150	5000	5420	6010[a]	5650	6530	5930
No. 9	4470	5360	6430	6170[a]	5420	5750	5480
No. 10	4980	6170	6220	6860[a]	6580	6770	5360
No. 11	4760	6160	6120	5810[a]	5310	5440	4470
No. 12	4090	5590	6090	5580[a]	4980	6550	5580
Average	4310	5310	5620	5670	5180	5610	5220

[a] Specimens soaked in water 24 hr. before test at this age and thereafter.
[b] Average of 2 tests after 3 months for cement No. 1.

conditions for long periods of time. These strength characteristics are illustrated by six age-strength charts in which the strength values used are the arithmetic means obtained by averaging the concrete strength data for the twelve cements at the various ages. In other words each point on these charts is the average concrete strength value for 36 test specimens which includes three specimens for each of twelve different cements. Although there may be some questions raised about the significance of these average values, they appeared to be the best practical way to summarize the findings of the test program. Actually each cement tested is a separate series in itself and it can readily be seen from

TABLE V.—TYPE III CEMENT CONCRETE.

Compressive concrete strengths of 3 by 6-in. cylinders, psi.

Damp Room Storage

Cement	1 day	7 day	28 day	3 month	1 yr.	2 yr.	4 yr.	8 yr.	12 yr.	16 yr.
No. 13	1270	4830	6070	6500	6190	5930	6090	6470	6400	6570
No. 14	1330	4970	5790	6150	6550	6370	6270	6660	6690	6710
No. 15	1130	3440	4850	5440	5650	5700	5920	6030	6470	6140
No. 16	1040	3550	4960	5720	6260	6400	6500	6310	6630	6660
No. 17	1380	3700	5210	5660	5890	6050	6180	6260	6310	6450
No. 18	1260	3880	5100	5610	5630	6180	6580	6730	6850	6850
No. 19	1290	4460	5710	6360	5980	6350	6370	6690	6870	7000
No. 20	982	4250	5790	6720	6590	7070	6990	7100	7260	7110
No. 21	1230	4890	6180	6810	6550	6650	6940	6890	7220	7330
No. 22	1040	3890	5770	6710	6300	6870	7240	7180	7400	7340
No. 23	1200	4950	5880	6370	6250	6560	6710	6620	6990	6910
No. 24	1080	5080	6320	6450	6430	6580	6840	6720	7320	6770
Average	1190	4320	5640	6210	6190	6390	6550	6640	6870	6820

Indoor Storage (Laboratory Air) After 7 days Curing

Cement	3 month	1 yr.	2 yr.	4 yr.	8 yr.	12 yr.	16 yr.
No. 13	5370	5250	5670	6080	7160	6510[a]	7020
No. 14	5090	5110	5390	6030	6720	6270[a]	6670
No. 15	4840	5180	5390	5820	6030	5680[a]	6420
No. 16	4830	5280	5650	5990	6840	6160[a]	6380
No. 17	5040	5590	5930	6270	6780	6170	6540
No. 18	5340	5060	5470	4680[a]	4870	5650	5690
No. 19	5620	5660	6240	5260[a]	6080	6170	7060
No. 20	5620	5360	6220	5260[a]	5860	6160	7040
No. 21	5930	5600	6060	5040[a]	5820	6720	6820
No. 22	5810	5510	6360	5010[a]	5660	6250	6890
No. 23	5180	5010	5560	4690[a]	5440	6450	6660
No. 24	6340	6470	6300	5650[a]	6320	6900	7110
Average	5420	5420	5850	5480	6130	6260	6690

Outdoor Storage (Natural Weathering) After 7 days Curing

Cement	3 month	1 yr.	2 yr.	4 yr.	8 yr.	12 yr.	16 yr.
No. 13	6580	5520	6180	6190	5980	5420[a]	5530
No. 14	6760	5570	5880	6040	5240	4680[a]	4780
No. 15	5140	5180	5150	6250	4790	5790[a]	5800
No. 16	5550	5570	5770	6350	5400	5130[a]	5780
No. 17	5730	5530	5690	6340	5570	5200[a]	5280
No. 18	4940	5180	6560	6480[a]	6940	6590	6320
No. 19	6000	6040	6380	6350[a]	5520	5480	5520
No. 20	6280	5500	6950	6690[a]	6780	6070	6070
No. 21	7140	5980	6710	6650[a]	6100	6700	6420
No. 22	6060	5630	6720	6600[a]	6730	6950	7060
No. 23	6330	5380	6260	6240[a]	6340	6990	6810
No. 24	6150	6080	6420	6600[a]	6260	6930	6480
Average	6060	5600	6220	6400	5970	5990	5990

[a] Specimens soaked in water 24 hr. before test at this age and thereafter.

a study of the tables that there are marked differences among some cements according to their various chemical and physical attributes.

Figures 1, 2, and 3 illustrate the effect of the various conditions of curing on the long-time concrete strengths for cements of types I, III and II, respectively.

Figures 4, 5, and 6 show the average strengths for the three types of cement when in fog room storage, indoor storage and outdoor storage, respectively.

Discussion of Results

The lines of Fig. 1 chart the general progression of average strength of the twelve type I cements under ideal and

TABLE VI.—TYPE II CEMENT CONCRETE.
Compressive strengths of 3 by 6-in. cylinders, psi.

Damp Room Storage

Cement	1 day	7 day	28 day	3 month	1 yr.	2 yr.	4 yr.	8 yr.
No. 25	320	1620	3730	5310	5510	5690	6250	6400
No. 26	423	2270	4720	5310	5690	6480	6780	7220
No. 27	402	2120	4720	5840	6100	6580	6960	7260
No. 28	626	2720	4790	5680	5820	6460	6520	6740
No. 29	435	2260	5300	6110	6450	6360	6590	6860
No. 30	453	1930	4610	5790	5980	6430	6750	6550
No. 31	286	2290	5370	5900	7050	6570	6990	7050
No. 32	390	1430	2870	5570	6470	6920	7030	7270
No. 33	452	2400	4530	5810	6140	6440	6390	7070
No. 34	436	2390	4120	5610	6000	6390	6800	6860
No. 35	588	2140	4130	4910	5750	6750	6710	6640
No. 36	367	2030	3450	5350	6110	6240	6660	6740
Average	430	2130	4360	5600	6090	6440	6700	6890

Indoor Storage (Laboratory Air) After 7 days Curing[a]

Cement	3 month	1 yr.	2 yr.	4 yr.	8 yr.
No. 25	2830	3140	3800	3830	4270
No. 26	3640[w]	2920	3220	3850	4380
No. 27	3550[w]	2810	3170	3620	4420
No. 28	2970	2990	3510	3740	4460
No. 29	2490	2640	2870	3060	3860
No. 30	2550	2550	3020	3750	3950
No. 31	2510	2540	2810	3540	3930
No. 32	2100	2200	2330	3010	3310
No. 33	2790	2970	3200	3920	4160
No. 34	2470	2410	2850	3220	3740
No. 35	3050	3200	3300	4010	4110
No. 36	2160	2330	2630	3020	3350
Average	2760	2730	3060	3550	4000

Outdoor Storage (Natural Weathering) After 7 days Curing[a]

Cement	3 month	1 yr.	2 yr.	4 yr.	8 yr.
No. 25	3960	4130	4480	5330	5640
No. 26	4360	5030	5200	5400	5620
No. 27	4360	5020	5540	6060	6720
No. 28	4330	4660	4520	5090	5790
No. 29	4650	5270	5370	5430	6070
No. 30	3740	5200	5640	5830	5940
No. 31	4560	5440	5430	6590	6190
No. 32	3620	4120	4970	5860	6340
No. 33	3900	4620	5520	5960	5780
No. 34	3280	5030	5320	5600	5530
No. 35	4690	4910	5520	5770	5960
No. 36	3340	4650	4780	5430	5350
Average	4070	4840	5190	5690	5910

[a] All specimens soaked 24 hr. in water before test.
[w] Tested air dry.

practical methods of curing. The indoor storage under generally dry conditions is seen to have arrested curing and materially delayed the development of strength; concrete stored outdoors took about two years to nearly attain the strength of standard curing.

Figure 2 demonstrates one of the chief benefits of high-early-strength cement because all three trend lines are so close together. This means that with type III cement high strength values can be realized with a short curing period. Incidentally, we believe that the acceptable progression of all cements in damp storage, as shown in Table V, precludes the possibility of systematic errors in testing procedure or equipment

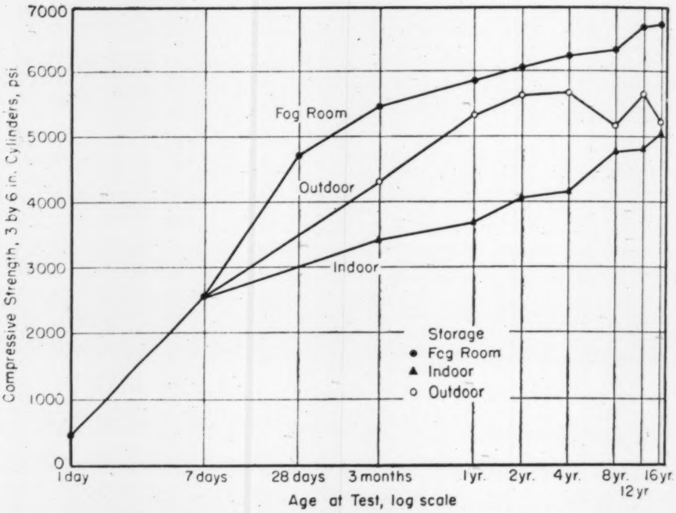

Fig. 1.—Effect of Storage Conditions Shown by Average Strength Values for Concrete with Type I Cement. (Nos. 1–12.)

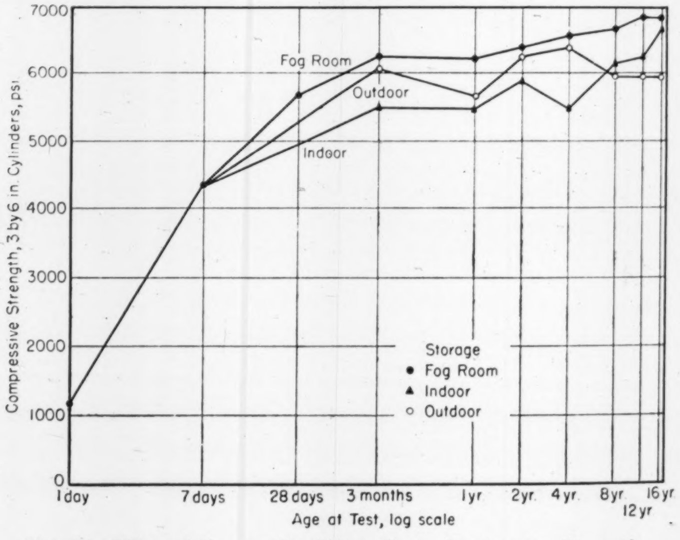

Fig. 2.—Effect of Storage Conditions Shown by Average Strength Values for Concrete with Type III Cement. (Nos. 13–24.)

or any other changes brought about by changes in personnel or the passage of time. Therefore the variations taking place in specimens stored outdoors appear to involve the relative resistance of the various concretes (or the respective cements) to natural weathering. It can be pointed out that according to Table V, cement No. 14 does not possess a good resistance to weathering and as a result appears to be falling off somewhat in strength, but it should be remembered the specimens broken during the last eight years were broken wet.

The twelve type II cements in Fig. 3 are of later vintage and naturally re-

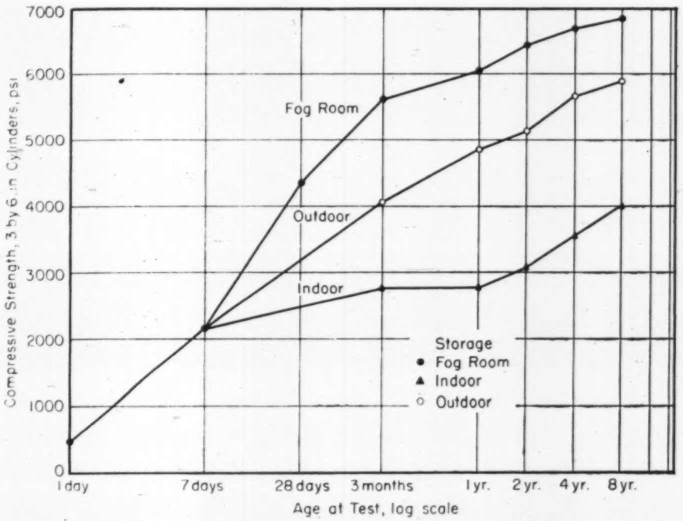

FIG. 3.—Effect of Storage Conditions Shown by Average Strength Values for Concrete with Type II Cement. (Nos. 25–36).

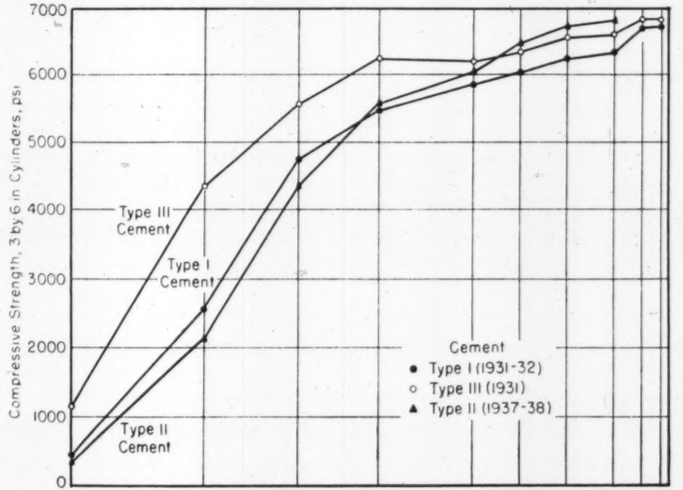

FIG. 4.—Age-Strength Relation for Concrete with Types I, II, and III Cements in Fog Room Storage.

flect some of the improvements in cement technology and specifications which developed during the decade before 1937. The duration of the test period is more limited but, based on the 8-yr. test results, all these cements have good strength records under each of the three storage conditions. The contrast of the lines for different modes of storage is interesting and, as might be expected, the slow hydrating character of the "moderate heat" or type II cements develops strength trends opposite to the ones discussed for high-early-strength concrete; hydration of the type II cements is arrested even more

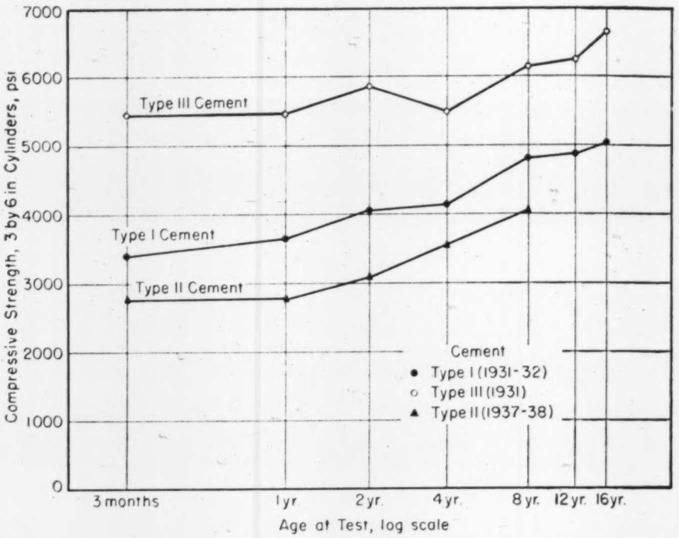

Fig. 5.—Age-Strength Relation for Concrete with Types I, II, and III Cements in Indoor Storage.

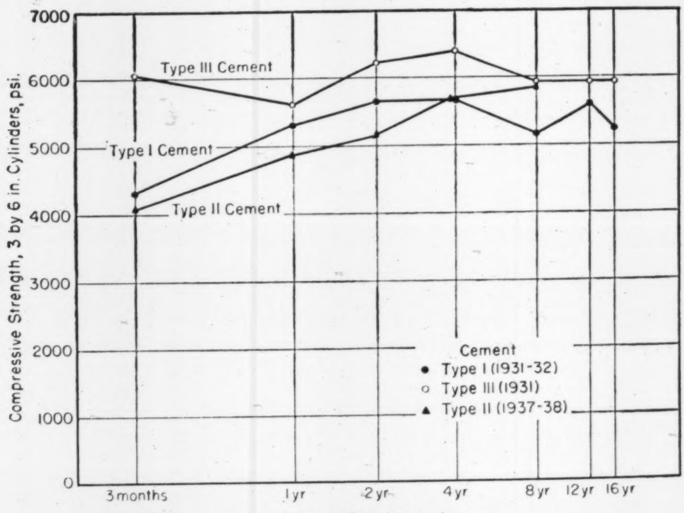

Fig. 6.—Age-Strength Relation for Concrete with Types I, II, and III Cements in Outdoor Storage.

definitely than for type I up to 1 yr. It is observed that types I and II and III cement concretes must have derived some moisture from the indoor air each year during the humid summer months in order to show strength increases indoors after 1 yr.

The three strength plots in Fig. 4 for fog room storage are congruous, show no signs of retrogression and appear to be still slowly gaining strength after 16 yr. for type I and type III cement and after 8 yr. for type II cement which seems to be nosing out in the home stretch. However, in making comparisons it should be remembered that the concrete with type II cements contained slightly less water, 0.25 to 0.5 gal. per sack, and that the type II cements were 1937–1938 vintage and probably averaged 200 to 300 sq. cm. per g. greater specific surface than the 1931–1932 model type I cements.

Figure 5 which shows the strength for the three types of cement obtained by inside storage is interesting in that all three graphs indicate that the specimens are still slowly gaining in strength. It appears that the strength of concrete with types I and II cements will not reach the strength obtained by high-early-strength cement under this storage condition. These data indicate that type III cement can be used to special advantage when the facilities for long-time moist curing are limited.

The outside storage strengths illustrated in Fig. 6 show that even though the concrete specimens with types I and III cement have experienced over 800 cycles of natural freezing and thawing during the past 16 yr., on the average no significant signs of retrogression are indicated. The concrete strength lines for these two cements have flattened out in this time and the concrete specimens with the type II cements are still gaining in strength after 8 yr. which includes approximately 400 cycles of natural freezing and thawing.

The potential strengths of the types I and III cements in 1931 were evaluated by the then Standard A.S.T.M. Tensile Strength Test C 77 – 30,[6] but when these 28-day mortar tensile strength values are compaied with 16-yr. compressive concrete strength values for the same cements there is apparently little or no correlation. The same situation exists when the 28-day specification test data for tensile and compressive mortar strengths obtained in 1937–1938 on the type II cements are compared with the 8-yr. compressive concrete strengths.

It is interesting to note the effect that the conditions of curing have on the strength of concrete containing cement No. 32. This cement is classified as a type II, although according to its composition it could probably be also classified as a type IV. The point of interest is that after 8 yr. of inside curing the concrete strength of this cement is the lowest of any of the type II group and after 8 yr. of fog room curing it is the highest of this same group.

SUMMARY AND CONCLUSIONS

1. High-early-strength cement concrete does not retrogress in strength as indicated by 16-yr. tests under various storage conditions.

2. Concrete cured under "inside" storage conditions in a relative low humidity atmosphere continues to gain slowly in strength up to the age limit of the test which was 16 yr. for concrete with types I and III cement and 8 yr. for concrete with type II cement.

3. In general, concrete containing types I and III cements cured under outside storage conditions for 16 yr. have endured approximately 800 natural cycles of freezing and thawing and have shown no appreciable signs of retrogression in compressive strength.

4. In fog room storage, which is usually considered as a standard curing condition, the concrete with types I and II cement approximates the strength of concrete with type III cement after about 2 yr.

5. Under the low humditiy inside storage conditions, concrete with type I cement does not appear to equal that with type III cement even after 16 yr.

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[6] This method has been discontinued and is superseded by A.S.T.M. Standard Method of Test for Tensile Strength of Hydraulic-Cement Mortars (C 190 - 44), 1946 Book of A.S.T.M. Standards, Part II, p. 80.

DISCUSSION

Mr. D. L. Bloem.[1]—I should like to ask Mr. McCoy a question.

He mentions 50 cycles of freezing and thawing a year, or a total of 800 cycles on these specimens. I wondered if he considers that actually represents 800 cycles of freezing and thawing similar to what would be produced in laboratory tests or whether it just represents a passage of air temperature through freezing 800 times.

Mr. W. J. McCoy (*author*).—The usual characteristics of freezing-and-thawing cycles under natural conditions are not the same as they are in typical laboratory testing.

A freezing-and-thawing cycle in laboratory testing of concrete is more or less of a shock treatment. For example, test specimens are usually maintained at a freezing temperature until a temperature equilibrium is reached; they are then subjected to a rapid temperature change and thawed until an equilibrium temperature is reached; they are then subjected to a rapid temperature change and frozen until a temperature equilibrium is reached and the cycle is thus repeated throughout the test.

The long-time test specimens did not experience 800 cycles of the type freezing and thawing that is done in laboratory testing but they did experience that number of cycles of freezing and thawing under natural weather conditions based on air temperature changes. This does not mean that the entire specimen went through all of the cycles. Frequently, the long-time test specimens would be only partially thawed or frozen. At times the specimens would be covered with snow, and occasionally the bottom sections would be frozen in ice and the top portion would be thawed due to the action of the sun. At times this natural weathering action was a rather strenuous treatment even though it may not have been as severe as laboratory freezing-and-thawing cycles. However, the natural weather conditions of the test are the conditions that an outdoor concrete structure would be exposed to, and therefore we believe the test results to be quite significant.

Mr. Meyer Hirschthal.[2]—I should like to know whether that 800 is the actual count of the weather changes—is that from an estimate of the number of cycles during the average year that you get or is this a count of actual changes in atmospheric conditions, in the period tested.

Mr. McCoy.—Daily temperature readings were recorded at 7:30 a.m. and 3:30 p.m. for 5 yr. and it was found that the air temperature passed through approximately 50 cycles of freezing and thawing each year. This average for 5 yr. was then used in computing the total number of cycles for the 8- and 16-yr. periods.

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[1] Assistant Director of Engineering, National Sand and Gravel Assn., Washington, D. C., and National Ready Mixed Concrete Assn.

[2] The Delaware, Lackawanna and Western Railroad Co., Hoboken, N. J.

THE DESIGN OF CONCRETE MIXES CONTAINING ENTRAINED AIR*

By Thomas H. Thornburn[1]

Synopsis

This investigation was undertaken in order to determine whether the mortar-voids method of concrete design originally suggested by A. N. Talbot and F. E. Richart could be adapted to the design of concrete mixes containing entrained air.

A preliminary study of the characteristics of mortar-voids curves obtained for mortars containing entrained air indicated that these curves cannot be used as a reliable basis for the design of concrete containing entrained air.

A study of the strength of controlled mortar and concrete mixes containing entrained air indicated that within the range of strengths commonly used for pavement concrete a significant linear correlation exists between the strength at a given age and the cement-space ratio.

It is suggested that theoretical mortar-voids curves for mortars containing entrained air may be prepared from the experimentally determined curves for mortars which do not contain entrained air. It is demonstrated how these theoretical curves may then be used to proportion a concrete mix of any desired strength provided the air entrained in the concrete corresponds to that assumed in the preparation of the theoretical design curves.

Tests on a series of laboratory mixes proportioned according to the suggested method indicated that the method is at least as accurate as the best methods used in the design of concrete mixes which do not contain entrained air.

The adoption of the use of concrete containing entrained air for highway pavements has created a demand for a new method of concrete design. Since none of the usual methods of concrete proportioning appear to be valid for mixes containing entrained air, most are now designed, at least in part, by trial. The purpose of this investigation was first to determine whether or not the mortar-voids method of design suggested by A. N. Talbot and F. E. Richart (1)[2] could be adapted to the design of mixes with entrained air. A synopsis of this method is given in the appendix to this paper. If mortar-voids design proved to be impractical, then the purpose was to discover a new and valid method of design for these mixes.

Investigation of Mortar-Voids Design Method

Standard Procedure:

In all mortar-voids tests the freshly-mixed mortar was compacted in a cylindrical mold having a diameter of 2 in. and a volume of approximately 200 ml.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27-July 1, 1949.

[1] Research Assistant Professor in Civil Engineering, University of Illinois, Urbana, Ill.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 935.

The mortar was placed in the mold in three equal increments and compacted by 25 blows per layer with a 1-in. cylindrical wooden tamper. The mortars prepared from the air-entraining cements were hand-mixed with a small trowel in an 8-in. enameled pan for a period of 3 to 4 min. after the water was added. The mixes prepared with normal portland cement and an air-entraining agent were mixed in a laboratory model countercurrent batch mixer designed by the Illinois Division of Highways. Unfortunately, this mixer was not available when the air-entraining cements were tested. A standard mixing time of 4 min., after the addition of water was maintained.

TABLE I.—RELATION BETWEEN MAXIMUM AIR VOIDS, RELATIVE WATER CONTENT AND SAND-CEMENT RATIO FOR 3 COMMERCIAL AIR-ENTRAINING CEMENTS, AND A BLENDED SAND.

a/c	Cement No. 1		Cement No. 2		Cement No. 3	
	Max. Air Voids	Relative Water Content	Max. Air Voids	Relative Water Content	Max. Air Voids	Relative Water Content
1.0	4.3	1.00	4.0	1.01	4.6	1.00
2.0	3.1	1.04	3.9	1.00	4.5	1.00
3.0	3.3	1.00	3.9	1.00	4.6	1.00
3.5	6.0	1.00	5.1	1.00	6.0	1.00
4.0	7.6	1.00	5.7	1.00	4.7	1.05
5.0	6.0	1.00	9.1	1.00	3.2	1.00

Mortars Made With Air-Entraining Cements:

In order to determine the reliability of the mortar-voids method, mortar-voids tests were made on three different brands of air-entraining cements when each was combined with a blended sand containing 80 per cent Wabash River sand and 20 per cent Lake Michigan dune sand. The results were quite disappointing as they indicated that by the use of accepted techniques it was impossible to obtain amounts of air in the mortar which would correspond to the amounts generally entrained in concrete

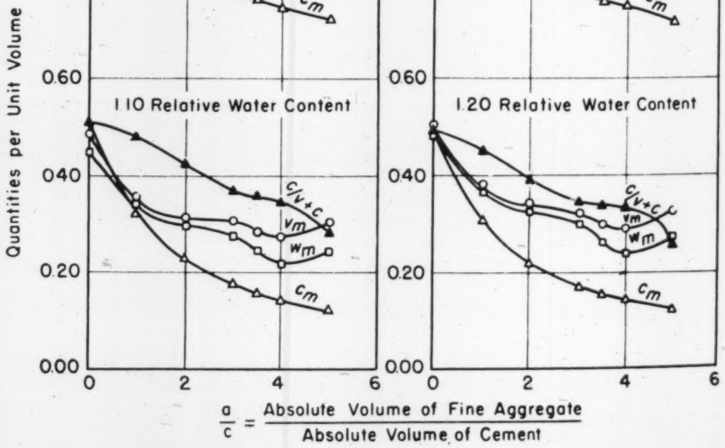

FIG. 1.—Typical Mortar-Voids Curves for Air-Entraining Cement and Blended Sand.

Furthermore, the greatest amounts of air were entrained in the mortars at or very near the basic water content for a given *a/c* ratio.[3] Table I shows the maximum air voids obtained for various mortar mixes of the cements and the relative water content at which each was obtained. Basic water content was taken as the volume of water which produced the minimum volume of mortar. It is apparent that high air contents were measured only in the leaner mixes which are seldom used in pavement concrete.

TABLE II.—VARIATION OF VOLUME OF WATER IN MORTAR AT MINIMUM VOLUME OF BATCH WITH SAND-CEMENT RATIO AND QUANTITY OF DAREX. UNIVERSAL ATLAS CEMENT AND ATTICA SAND MORTAR.

a/c	Quantity of Darex per Sack of Cement, cu. cm.				
	0	32	64	96	200
	w_m	w_m	w_m	w_m	w_m
1.50	0.269	0.254	0.250	0.275	0.274
2.34	0.247	0.233	...	0.228	0.229
3.00	0.245	0.240	0.236	0.217	0.206

Figure 1, which is typical of the basic mortar-voids curves which were obtained, shows that less than 4 per cent air was entrained when *a/c* was less than 3. The per cent of air is represented by the vertical distance between the curve for v_m and the curve for w_m.

There is some doubt as to whether the basic water content as defined by Talbot and Richart has any meaning when air-entraining cement is used. There is even more doubt that it could be reproduced with any reasonable degree of accuracy. This is due to the fact that the amount of air entrained varies with the method and the throughness of mixing as well as the temperature of the materials. The weight of a given volume of compacted mortar appears to be very sensitive to the amount of air entrained not only because of the reduction in weight due to the air, but also because of the variation in the workability of the mix with the amount of entrained air.

Mortars Made With Air-Entraining Agent:

Because of the difficulties which were encountered in using cement with interground air-entraining agent it was decided to test a standard portland cement with air-entraining agent added to the batch. The sand and cement used in this series were the same as those used in a series of bond tests of air-entrained concrete conducted by the University, namely, Wabash River sand from Attica, Ind., and Universal Atlas Cement. Darex was used as the air-entraining agent, and a series of mortar mixes was prepared using several different proportions of Darex to cement.

TABLE III.—RELATION BETWEEN MAXIMUM AIR VOIDS, RELATIVE WATER CONTENT AND SAND-CEMENT RATIO. UNIVERSAL ATLAS CEMENT AND ATTICA SAND MORTAR.

a/c	Quantity of Darex per Sack of Cement, cu. cm.							
	32		64		96		200	
	Max Air Voids	Relative Water Content	Max Air Voids	Relative Water Content	Max Air Voids	Relative Water Content	Max Air Voids	Relative Water Content
1.50	4.8	1.00	5.4	1.00	5.4	1.13	4.7	1.13
2.34	5.1	1.22	...	...	8.8	1.20	9.5	1.19
3.00	7.0	1.06	9.3	1.13	10.5	1.21	11.2	1.27

Table II shows how the basic water content of the mortar mixes was found to vary not only with the *a/c* ratio but also with the amount of Darex which was used. Table III shows that it was not possible to obtain as much as 6 per cent air in the richer mortar mixes with any reasonable amount of Darex. In general, the maximum amount of entrained air was found to increase as the mixes became leaner and as increasing amounts of Darex were added. However, the point of maximum air entrainment varied from a relative water content of 1.00 for rich mixes with small quantities of Darex to relative water content of 1.27 for leaner mixes with large quantities of Darex. Figure 2 shows typical mortar-voids curves for mixes containing 32 cu. cm. of Darex per sack. It can be seen that the air content varies with the relative water content as well as the a/c ratio.

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[3] See Appendix, p. 936.

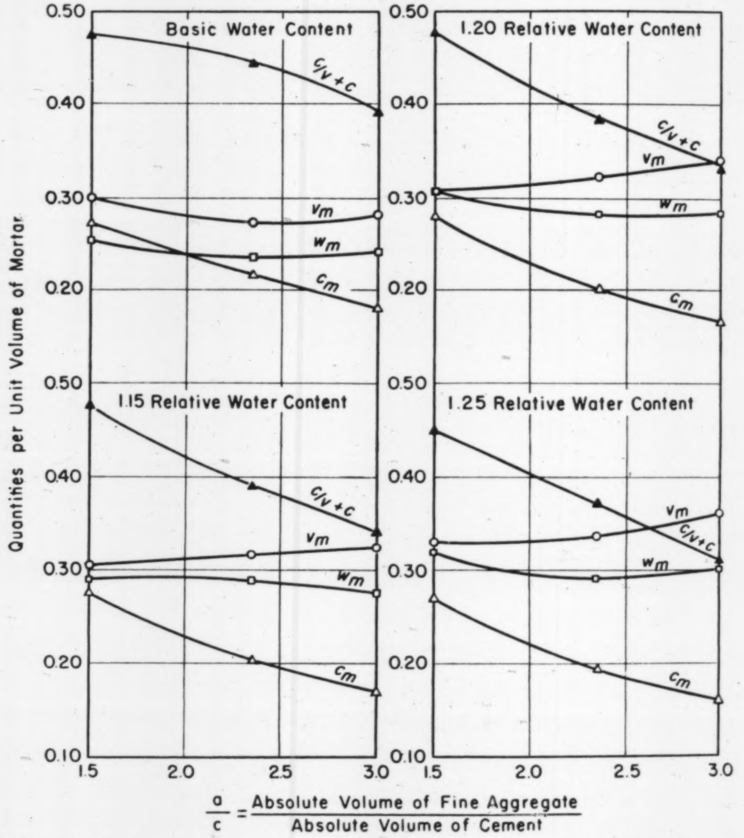

FIG. 2.—Mortar-Voids Curves for Universal Atlas Cement and Attica Sand with 32 cu. cm. Darex per sack of Cement.

Obviously it is not practical to base a method of concrete design on mortar-voids data such as those which have been presented. Design curves based on these data would prohibit the use of rich mixes if the proper air contents were to be obtained. This is contrary to the usual requirements for pavement concrete where high strength as well as resistance to scaling is desired. Results of both field and laboratory work have indicated that air contents of 3 to 5 per cent may be readily obtained in pavement concrete with relatively small quantities of Darex or other air-entraining agents. This would be roughly equivalent to air contents of 6 to 9 per cent in the mortar.

If it is not possible to produce small mortar batches with air contents within this range, there appears to be no experimental basis for mortar-voids design of concrete containing entrained air.

EFFECT OF ENTRAINED AIR ON COMPRESSIVE STRENGTH

Strength Tests of Concrete Cylinders:

After due consideration of the implications of the laboratory results obtained from the investigation of the mortar-voids relationships a new approach suggested itself. Fundamentally, the mortar-voids method of design is based on the relationship between the cement-space ratio, $c/(v + c)$, of a given mortar or concrete mix and its compressive strength at a given age. If this relationship remains the same whether the void space is almost all water as in ordinary concrete mixes or whether it is part water and part air as in air-entrained concrete mixes, a valid basis for design exists. A compilation of test data obtained in the undergraduate concrete laboratory courses at the University of Illinois indicated that the relationship was approximately the same for air-entrained concrete as for ordinary concrete, on the basis of 7-day strengths. The production of relatively large batches of concrete for a series of bond tests being conducted in the research laboratory (2) provided an ideal opportunity to check this relationship.

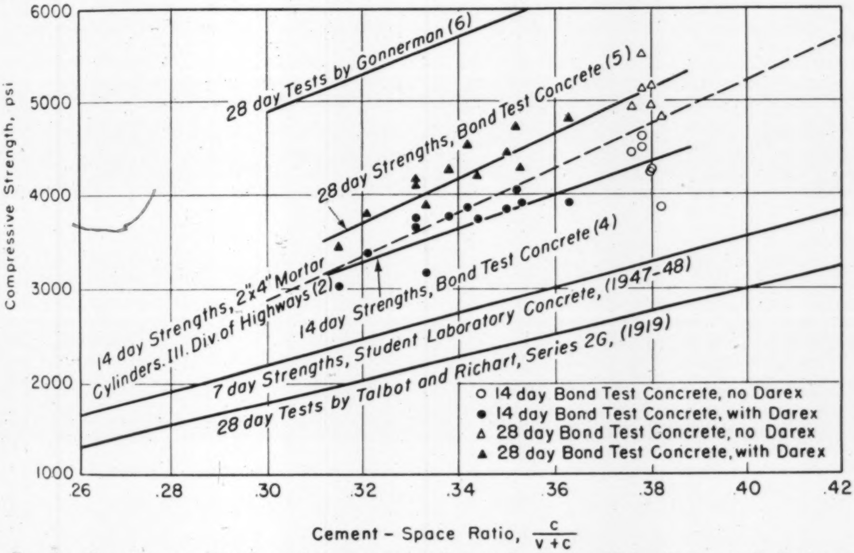

FIG. 3.—Cement-space Ratio and Compressive Strength of 6 by 12-in. Concrete Cylinders.

Figure 3 shows the relationship between the cement-space ratio and compressive strength of 6 by 12-in. concrete cylinders at seven days as determined from undergraduate student laboratory courses; at 14 days as determined for the concrete used in the bond tests; and at 28 days as determined for the bond test concrete. For reference, the same relationship is shown for the 6 by 12-in. concrete cylinders of the Talbot and Richart series 2G tested at 28 days and for the data published by Gonnerman (3) for 28-day strengths of air-entrained concrete produced by adding neutralized vinsol resin at the mixer. The Illinois Division of Highways design curve (4) based on strength of 2 by 4-in. ordinary cement mortar cylinders at a relative water content of 1.40 is also shown. In the analysis of the volume composition of each batch of bond test concrete, the total volume was computed theoretically from the weights of each of the materials and their specific gravities. This value was then adjusted according to the per cent of entrained air as measured with an air meter designed and used by the Illinois Division of Highways (5). The values of a, b, c, and w were then computed by dividing the volume of each of the components of the concrete by the adjusted volume of the batch. Each point plotted from data obtained in this investigation represents the average strength of three cylinders.

A study of Fig. 3 shows that the relationship between strength and cement-space ratio is a straight line within the range commonly used for pavement concrete. It is also evident that the line which best fits the data for 14-day strengths closely resembles the Illinois Division of Highways design line based on 14-day mortar strengths for a relative water content of 1.40. It is remarkable that the lines obtained from five different sources all have approximately the same slope.

Strength Tests of Mortar Cylinders:

Another check on the validity of the compressive strength cement-space ratio relationship was obtained from tests on a series of mortar mixes prepared in the laboratory mortar mixer. Six specimens of the mortar were molded for each batch according to the standard procedure outlined for the mortar-voids tests. The volume of each batch was computed from the weights and specific gravity of the materials used and the unit weight of the sample as measured in the 200-ml. mold. From this information and the batch weights, the values of a_m, c_m, v_m, w_m and $c_m/(c_m + v_m)$ were determined for each batch.

In conjunction with the bond tests a sample of concrete from each batch was sieved through a No. 4 mesh vibrating screen. On the first few batches the air content was determined with the air meter after which 2 by 4-in. mortar cylinders were then prepared for test at 14 days. On later batches a unit weight test of each extracted mortar was made using the mortar-voids procedure of compaction. The weight of a one-bag batch of the extracted mortar was computed by summing the weights of cement, sand, and water which went into a one-bag batch of the concrete mix. This value was then divided by the unit weight of the extracted mortar in order to find the volume of the one-bag mortar batch. The above procedure is later referred to as the gravimetric method. The volume of a one-bag batch of extracted mortar was also calculated by subtracting the computed volume of coarse aggregate from the computed volume of the total batch of concrete and then correcting the difference for the per cent of air in the mortar as determined by the air meter.

The volume of a one-bag batch of a given extracted mortar as calculated from the air-meter air content was considerably greater than that computed by the gravimetric method. Furthermore, it was later found that there was no good correlation between the compressive strength and the cement-space ratio when the value of $c/(v + c)$ was computed from the air-meter data. When the data for extracted mortars were checked against similar data for the mortar mixes, there was good agreement where $c/(v + c)$ of the extracted mortar had been obtained by the gravimetric determination but poor agreement when it had been based on the air-meter determination. On the basis of these comparisons, it was concluded that the air contents of the extracted mortars as determined by the air meter were probably incorrect. This was thought to be due to faulty placement of the mortar in the air-meter bowl which allowed large air voids to be trapped in the mortar. This is verified to some extent by the fact that the air meter registered mortar air contents of about 2 per cent when no Darex had been used in the mix.

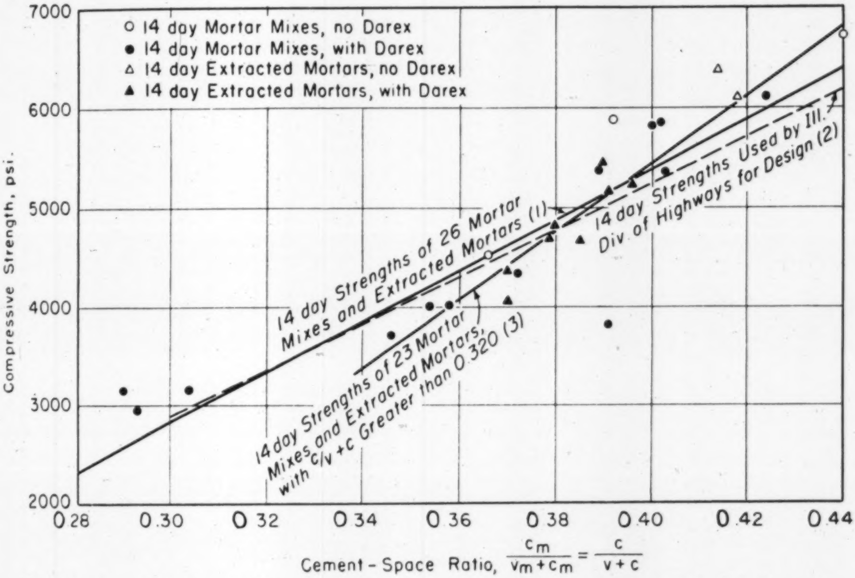

FIG. 4.—Cement-space Ratio and Compressive Strength of 2 by 4-in. Mortar Cylinders.

In Fig. 4 the data plotted consist of those obtained from the laboratory mortar mixes and from the extracted mortars where gravimetric air determinations were made. Each point on this graph represents the average strength of six cylinders. The Illinois Division of Highways mortar design line is plotted for reference.

It may be seen that within the range of strengths commonly specified for pavement concrete a linear relationship exists between the 14-day compressive strength of 2 by 4-in. mortar cylinders and the cement-space ratio of the mix. The slope of the line derived from these data is somewhat greater than the slope of the mortar design line used by the Illinois Division of Highways provided the mixes with a $c/(v + c)$ of less than 0.320 are not considered. If the data from all of the mortar specimens are analyzed, the line which best fits the data very closely approximates the design line of the Illinois Division of Highways.

Analysis of Test Results:

In order to determine the line of best fit for the various experimental data they were subjected to statistical analysis. Table IV shows the results of this analysis in terms of the equation of the line, the slope of the line, the standard error of prediction and the linear correlation coefficient corrected for small samples. In addition, statistical methods were used to test the significance of the correlation coefficient. For reference, Table IV also contains the equation and slope of the Illinois Division of Highways mortar design line at a relative water content of 1.40 and of the line determined by Gonnerman for concrete with neutralized Vinsol resin added at the mixer. The line numbers are the same as those shown in parenthesis in Figs. 3 and 4.

The information presented in Table IV shows that the equation for line No. 1 which best fits all the data obtained on mortar strength tests is not very different from line No. 2 which is one used as a basis for design by the Illinois Division of Highways. However, line No. 3 which is based only on specimens with cement-space ratios in excess of 0.320 has a much greater slope than either of these. Actually, this is not particularly significant because within the range of strength of pavement concrete all three of the lines intersect. However, line No. 3 would certainly be highly in error if used for the design of mortars with 14-day strengths below 3500 psi.

TABLE IV.—RELATIONSHIP BETWEEN COMPRESSIVE STRENGTH AND CEMENT-SPACE RATIO FROM VARIOUS TESTS OF MORTAR AND CONCRETE CYLINDERS.

Line	Source of Data	Predicting Equation	Correlation Coefficient	σ_e, psi.	Slope of Line[a]
No. 1...	14-day strength of 26 mortar mixes and extracted mortars.	$\text{Strength}_{(\text{psi.})} = 25\,679 \left(\frac{c}{v+c}\right) - 4876$	0.92	406	25 679
No. 2...	14-day strength of mortars with relative water content of 1.40. Illinois Division Highways design curve[b]	$\text{Strength}_{(\text{psi.})} = 23\,375 \left(\frac{c}{v+c}\right) - 4140$	...	...	23 375
No. 3...	14-day strength of 23 mortar mixes and extracted mortars, where $c/(v + c) > 0.320$	$\text{Strength}_{(\text{psi.})} = 34\,242 \left(\frac{c}{v+c}\right) - 8263$	0.91	365	34 242
No. 4...	14-day strength of 18 batches of bond-test concrete.	$\text{Strength}_{(\text{psi.})} = 17\,656 \left(\frac{c}{v+c}\right) - 2345$	0.88	196	17 656
No. 5...	28-day strength of 18 batches of bond-test concrete	$\text{Strength}_{(\text{psi.})} = 24\,028 \left(\frac{c}{v+c}\right) - 3978$	0.96	147	24 028
No. 6...	28-day strength of concrete reported by H. F. Gonnerman[c]	$\text{Strength}_{(\text{psi.})} = 20\,500 \left(\frac{c}{v+c}\right) - 1250$	...		20 500

[a] Slope expressed as psi. compressive strength per unit cement-space ratio.

[b] Manual of Instruction for Proportioning Engineers, Division of Highways, State of Illinois, April, 1938.

[c] "Tests of Concretes Containing Air-Entraining Portland Cements or Air Entraining Materials Added to Batch at Mixer," *Journal*, Am. Concrete Inst., Vol. 15, No. 6, June, 1944.

Line No. 4 representing the 14-day strengths of the bond test concrete specimens has a slope somewhat less than lines 1, 2, or 3, but in general agreement with lines 1 and 2 in the range of strength of 3000 to 4000 psi. This would seem to indicate that line 3 is not satisfactory for estimating the strengths of concrete at 14 days. However, Fig. 3 shows that the wide scattering of points representing the specimens which did not contain Darex has had an undue influence on determining the slope of line 4. For this reason it is doubtful if line 4 should be used as a basis for design of concretes containing entrained air.

Line No. 5 which is based on the 28-day strengths of the bond test concrete specimens has approximately the same slope as lines 1 and 2, but lies slightly above them. This is to be expected and serves to enhance the value of the first two lines as a basis for design.

Line No. 6, which was published by Gonnerman, has a slope somewhere between that of lines 1, 2, and 5 and line 4, but more nearly approaches the latter.

However, the strengths predicted by line 6 are so far above those ordinarily obtained even in the laboratory that it has little meaning for design purposes.

On the basis of the 14-day strengths of concrete cylinders prepared from the bond-test concrete and those which will be discussed later, it is believed that either line 1 or line 2 may be used to design satisfactory concrete mixes containing entrained air. Whichever line is used, a value of $c/(v + c)$ should be selected which will produce a mortar with a compressive strength about 500 psi. higher than the average strength desired in the concrete. Ordinarily, this will provide a sufficient factor of safety to allow for random variations in the mix as well as variations in the desired air content.

Since a linear correlation coefficient of 1.00 indicates perfect correlation with every point falling on a straight line, all of the coefficients listed in Table IV show that the corresponding equations are quite accurate representations of the data which were analyzed. This was verified by tests of statistical significance of the correlation coefficients, which in every case shows that the chances are less than 1 in 100 that there is not a linear correlation between the items correlated.

The value of the standard error of prediction, σ_e, is an expression of the random variation of the individual points around the predicting line. For example, if several batches of mortar were prepared from the materials used in this investigation and using Eq. 1 as a basis for design, approximately 66 per cent of the specimens would be expected to have strengths within 406 psi. of the design strength. It is interesting that the standard error of prediction for the 28-day strengths of the concrete was the smallest one obtained. This would seem to indicate that variations in strength between concrete from different batches tend to be minimized as the concrete ages.

All of the experimental data obtained in the described tests both with mortars and concretes have indicated that within the range of strengths of pavement concrete a significant linear relationship does exist between compressive strength and cement-space ratio whether or not air is entrained in the mixture. Furthermore, it has been found that for the particular combination of cement and aggregate which was tested, this relationship differs very little from one used for concrete design by the Illinois Division of Highways. Only further experimentation can determine whether this same relationship is valid for all cements and types of aggregates, but there is no reason to believe that it will not be. Assuming that this relationship does hold good with few or no exceptions, a valid basis for the design of concrete mixtures containing entrained air is already in existence. There remains only the problem of selecting the correct values of a/c and w to be used with a given value of b in order to obtain the $c/(v + c)$ required for design strength.

THEORETICAL ANALYSIS OF MORTAR-VOIDS DESIGN

The laboratory mortar-voids tests have indicated that it is not possible to obtain air contents in mortar mixes which correspond to the air contents obtained in mortars of the same composition when mixed with coarse aggregate in a concrete mixer. However, it is possible to compute the volume composition of a mortar in a concrete of known composition by assuming all the air to be in the mortar. Conversely, it is possible to compute the composition of a given concrete knowing the composition of the mortar and the amount of coarse aggregate used. It is also possible to compute the theoretical volume composition of any mortar by assuming any desired air and water content. This suggests a solution to the general problem under consideration.

Suggested Procedure for Concrete with Entrained Air:

The preceding paragraph suggests that theoretical or synthetic mortar-voids curves may be constructed for a mortar having any desired air content. As an example, let us assume that an air content of 7 per cent is desired in the mortar.

First, the basic mortar-voids curves should be experimentally determined for the selected cement and fine aggregate without an air-entraining admixture. From these curves the values of w_m and v_m give the actual air content of the mortar. Now the air content of each mortar should be arbitrarily increased to 7 per cent. The volume of the mortar is thus increased by the amount of the arbitrary increase in air, but knowing this, corrected values of v_m, c_m and $c_m/(v_m + c_m)$ can be computed. New curves may then be plotted which represent a mortar with 7 per cent air regardless of how the air was entrained. The air content of the concrete containing this mortar should equal (1-b) times the air content of the mortar.

The air content selected for the theoretical design curves may be chosen in one of two ways. If it is desired to have exactly 4 per cent air in the fresh concrete, it is simple to calculate the required air content of the mortar knowing the value of b which is to be used. On the other hand, more useful mortar-voids curves may be obtained by arbitrarily choosing an average value for the percentage of air in the mortar which will cover a relatively wide range of useful b values. This is possible since the air content of the concrete is usually specified to be within a range of 3 to 5 per cent. Thus, if a mortar air content of 7 per cent is chosen for the design curves, a concrete containing this mortar and having a b value of 0.57 would contain 3 per cent air, but one having b equal to 0.29 would contain about 5 per cent air.

Advantages and Limitations:

It is readily apparent that this method of design will require that the air content of concrete in the field be rather closely controlled in order to produce the design yield and strength. On the other hand, it is felt that this is much more practicable than to design on the basis of laboratory conditions which can seldom be reproduced in the field.

This method of design has the virtue of requiring no additional laboratory work on the part of organizations which have accumulated experience and data with the mortar-voids method. It is only necessary to modify the basic mortar-voids curves determined for various combinations of cement and fine aggregate in terms of the desired mortar air content. The corresponding concrete air content may then be obtained in the field by the use of any air-entraining agent and method of mixing which appears desirable. It is not known whether this method may be applicable to cements which contain interground air-entraining agent. It seems possible that basic mortar-voids data could be obtained on samples of the same cement not containing the interground agent and modified to include the required percentage of entrained air. This, however, remains to be investigated. In any event, the field control would not be positive, and it is evident that the design procedure will be more accurate when the air-entraining agent can be added at the mixer to produce exactly the desired amount of entrained air.

PROPOSED DESIGN PROCEDURE

Preparation of the Mortar-Voids Curves:

According to the suggested procedure, a theoretical mortar-voids design curve

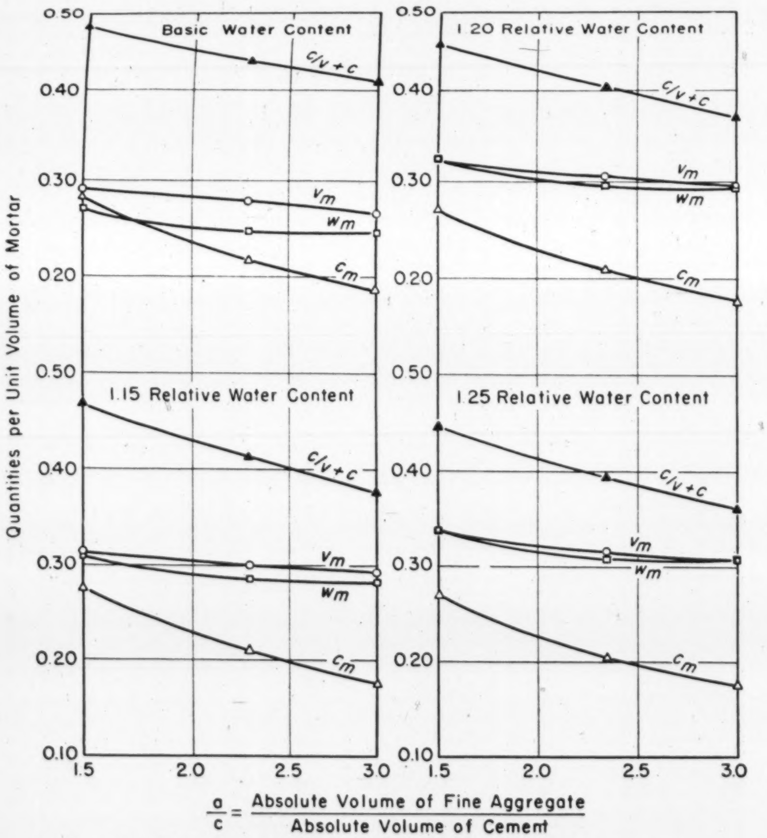

FIG. 5.—Experimental Mortar-Voids Curves for Universal Atlas Cement and Attica Sand.

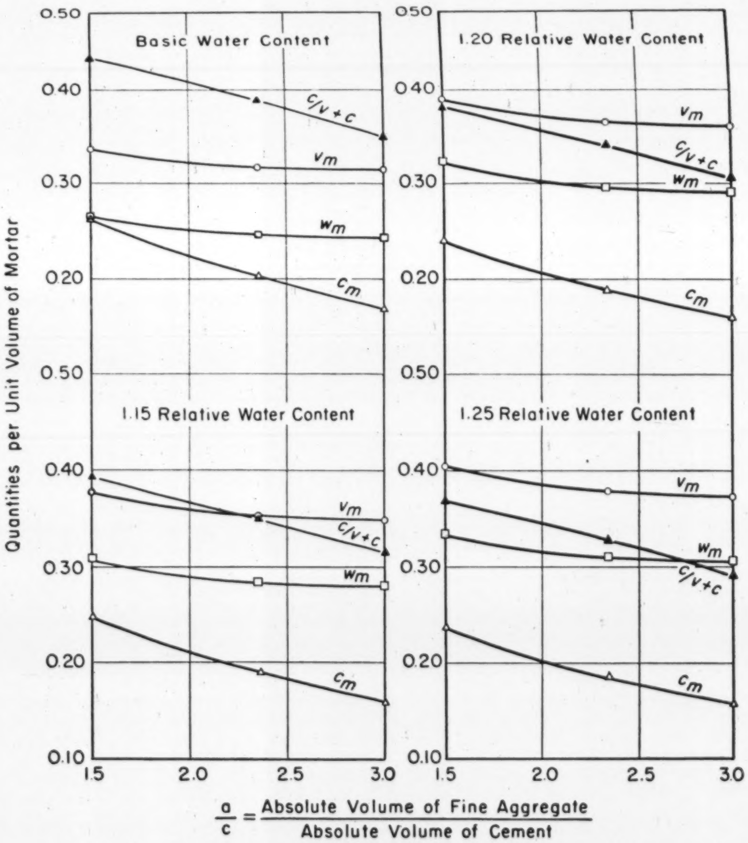

FIG. 6.—Theoretical Mortar-Voids Curves for Universal Atlas Cement and Attica Sand with 7 per cent Air.

TABLE V.—ESTIMATED VALUE OF RELATIVE WATER CONTENT REQUIRED FOR A GIVEN SLUMP AT A GIVEN AIR CONTENT IN FRESH CONCRETE.

Slump, in.	Relative Water Content	
	3 to 4 Per cent Air	5 to 6 Per cent Air
1 to 3	1.15	1.10
4 to 6	1.20	1.15

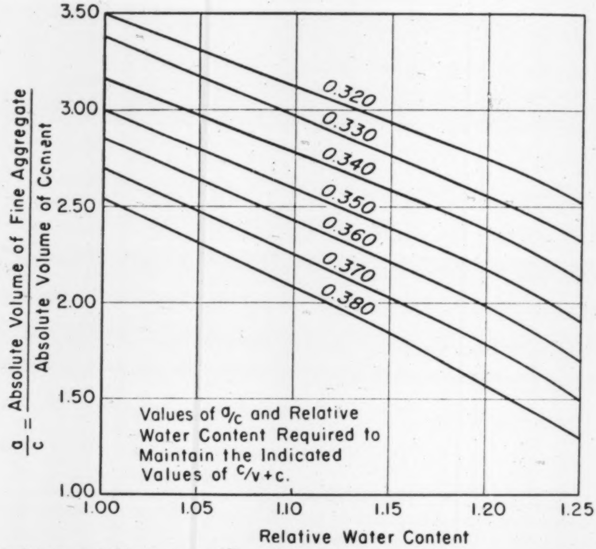

FIG. 7.—Consistency Adjustment Chart for Universal Atlas Cement and Attica Sand.

for a given mortar air content can be produced from the curve relating w_m to a/c for a given sand and cement at a given relative water content. The selected air content is added to the value of w_m for each representative a/c value, and the new v_m curve is drawn. Knowing a/c and v_m, it is possible to calculate c_m and finally $c_m/(v_m + c_m)$. By selecting representative a/c values, the new design curve for $c_m/(v_m + c_m)$ may then be plotted. For example, let us suppose that for a given combination of sand and cement at basic water content the experimentally determined value of w_m equals 0.270 at an a/c value of 1.5. Assuming that it is desired to find the value of $c_m/(v_m + c_m)$ for 7 per cent air entrained in the mortar. Let p_m equal the assumed air content of the mortar.

Then $v_m = w_m + p_m = 0.270 + 0.070 = 0.340$

Since $a_m = 1.5\, c_m$

and $a_m + c_m + v_m = 1$

then $1.5\, c_m + c_m + 0.340 = 1.00$

or $2.5\, c_m = 0.660$ and $c_m = 0.264$

Finally, $c/(v + c) = c_m/(v_m + c_m) = 0.264/(0.340 + 0.264) = 0.437$

Figure 5 shows the experimentally determined curves for Universal Atlas Cement and Attica, Ind. sand at relative water contents of 1.00, 1.15, 1.20, and 1.25 respectively. Figure 6 shows the theoretical curves for the same materials at the same relative water contents with an assumed air content of 7 per cent in the mortar. In both sets of curves the relative water contents have exactly the same meaning since they are based on the values of w_m as determined experimentally on mortars which contain no entrained air.

Selection of the Relative Water Content:

There now remains only one problem of design, that of selecting the correct relative water content for a given concrete consistency, and this must be determined by experience as in the present method of mortar-voids design employed for normal concrete mixes. There are, however, two factors to be considered which alter the choice of relative water content as compared to normal mixes. The inclusion of air in concrete produces a plastic mix which is usually more workable than a normal mix of equivalent consistency as measured by the slump test. This factor has the effect of decreasing the slump required for a given job. Furthermore, when air is added to a concrete of given relative water content and slump, the total voids are increased, and consequently the slump is increased. This factor thus has the effect of decreasing the relative water content required for a given slump. Because of the operation of these two factors, it is extremely unlikely that any direct correlation based on past experience with normal concrete may be used to specify the relative water content needed for a concrete containing entrained air. As a rough guide the data presented in Table V may be used. These are based on the relative water contents and slumps obtained for the concrete mixes prepared for the bond tests. It must be stressed that this table is tentative as well as quite incomplete.

If the desired consistency is not obtained for a given mix through the use of the table, then a graph similar to Fig. 7 may be used. The data for each curve was obtained from Fig. 6 by picking off the values of a/c and relative water content at a constant value of $c/(v+c)$. It is possible to draw a family of curves of this type which may be used to adjust the consistency of the mix without affecting its compressive strength.

Sample Mix Design:

Let us now see how it is possible to design a concrete mix containing entrained air on the basis of the method which has been presented. Problem: To design a concrete which will have a compressive strength of 4500 psi. at 14 days using Universal Atlas Cement and sand and gravel from Attica, Ind. This mix should have a slump of 2 in. and contain approximately 4 per cent entrained air.

Given sp. gr. cement = 3.10,
sp. gr. sand = 2.65, and
sp. gr. gravel = 2.70.
Assume $b = 0.430$

From Table V relative water content of 1.15 is indicated for a 2-in. slump. In the analysis which follows, the standard Talbot-Richart nomenclature is used with the exception that a new term, p, has been added. It is equal to the absolute volume of air voids in a unit volume of freshly made concrete. Thus $p = v - w$.

Solution:

From Fig. 4, curve 1, a $c/(v+c)$ value of 0.380 is indicated for a 14-day compressive strength of 4850 psi., which allows a factor of safety of 350 psi. above the desired average compressive strength. From Fig. 6, $a/c = 1.83$ at 1.15 relative water content and $c/(v+c)$ of 0.380 also from Fig. 6

$$w_m = 0.296 \text{ and } v_m = 0.366$$
$$(1 - b) = 1 - 0.430 = 0.570$$

Thus $w = 0.296 \times 0.570 = 0.169$
$v = 0.366 \times 0.570 = 0.208$
$p = 0.208 - 0.169 = 0.039$
also $a = 1.83\,c$
and $a + c = 2.83\,c = 1 - v - b = 1 - 0.028 - 0.430 = 0.362$
Thus $c = 0.362/2.83 = 0.128$
and $a = 1.83 \times 0.128 = 0.234$

This mix by solid volume then becomes 0.128:0.234:0.430 and

$0.128 \times 3.10 \times 62.4 = 24.7$ lb. cement
$0.234 \times 2.65 \times 62.4 = 38.7$ lb. sand
$0.430 \times 2.70 \times 62.4 = 72.4$ lb. gravel
$0.169 \times 62.4 = 10.54$ lb. water

The mix by weight is thus

24.7:38.7:72.4 or 1:1.57:2.93

w/c by weight = 10.54/24.7 = 0.427 lb. per lb. which is equivalent to 4.8 gal. per sack.

Test Results:

A mix of the above proportions was prepared in the laboratory in a Lancaster type SW counter-current mixer using Darex at the rate of 20 cu. cm. per sack of cement and 4-min. mixing time. The fresh mix was found to have a slump of 3 in. and a net air content of 3.7 per cent. Four 6 by 12-in. cylinders were prepared by vibrating the concrete into the molds. These test cylinders were found to have 14-day compressive strengths of 4370, 4650, 4160, and 4680 psi. for an average strength of 4470 psi.

TABLE VI.—DESIGN DATA AND TEST DATA FOR SEVERAL MIXES WHICH WERE PREPARED TO TEST THE SUGGESTED DESIGN PROCEDURE.

Mix.	Design Strength, psi.	Design Slump, in.	Relative Water Content	Design Air Content, per cent	Amount of Darex per Sack of Cement, cu. cm.	b	Design $\frac{c}{v+c}$	Mix Ratio	Water-Cement Ratio, w/c, by weight	Test Values			Corrected $c/v+c$	Estimated Strength, psi.
										Slump, in.	Net Air, per cent	Average Strength, psi.		
D-1	3500	2	1.15	4.0	32	0.440	0.330	1:2.34:3.94	0.525	2.75	6.4	3080	0.305	3000
D-2	4000	4	1.20	4.0	32	0.440	0.355	1:1.76:3.33	0.480	4.75	6.5	3410	0.324	3400
D-2-2	4000	4	1.20	4.0	16	0.440	0.355	1:1.76:3.33	0.480	5.50	3.3	3460	0.360	4100
D-3	4500	2	1.15	4.0	20	0.430	0.380	1:1.57:2.93	0.427	3.0	3.7	4470	0.380	4500
D-4	4500	4	1.20	4.0	20	0.430	0.380	1:1.33:2.76	0.435	6.25	3.7	4560	0.380	4500

Table VI shows the design data and test data for several mixes which were prepared to test the suggested design procedure. All of these mixes were prepared in batches of slightly more than 1 cu. ft. in the Lancaster Mixer. It can be seen that the amount of air entrained in mixes D-1 and D-2 was too great for the design strength to be obtained. The corrected value of $c/(v + c)$ is based on the air content which was actually obtained and the estimated strength was based on this corrected value. It is apparent that the actual 14-day strength of the concrete checks very closely with the estimated strength for all batches except D-2-2. The reason for the discrepancy in this particular batch is not known. Perhaps it represents the amount of error which may be expected with this method of design. If so, it appears that it will be necessary to design for about 4000-psi. concrete in order to be assured of a 14-day strength of at least 3500 psi. This is in line with the present Illinois Division of Highways design procedure for normal concrete with no entrained air. It is also possible that the low strength of this particular batch may have been due to an error in weighing the mixing water or the cement; however, there is no way to be sure. Only further tests can correctly establish the inherent error of this method of design. It should be remembered that any excess of air over the design air content will lower the test strength of the concrete. In order to be sure that every batch of concrete will meet any given strength specifications, it will undoubtedly be necessary to design the batches for strengths about 500 psi. above specification in order to allow for some variation in the air content produced under field conditions.

SUMMARY AND CONCLUSIONS

1. A study of the characteristics of mortar-voids curves determined for mortars containing entrained air has indicated that these curves cannot be used as a reliable basis for the design of concretes containing entrained air. This is due to the fact that the amount of air entrained in the mortar is determined by

a variety of factors, such as method of mixing, temperature of the mix, and richness of the mix. Furthermore, it has not yet been found possible to entrain in the richer mortar mixes the amounts of air required for design purposes.

2. A study of the strengths of controlled mortar and concrete mixes containing entrained air has indicated that within the range of strengths commonly used for pavement concrete a significant linear correlation exists between the strength at a given age and the cement-space ratio. Furthermore, this linear relationship very closely approximates one used by the Illinois Division of Highways in its present design procedure. Apparently the relationship between compressive strength and cement-space ratio is the same whether the voids in the mix are completely filled with water or whether they are filled partly with water and partly with air.

3. It is possible to prepare theoretical mortar-voids curves incorporating any desired percentage of entrained air by a series of computations based on the mortar-voids curves determined experimentally from a series of mortar-voids tests on any given sand and cement.

4. These theoretical curves may be used to determine the correct proportions of concrete materials required to produce a mix of any desired strength provided the air entrained in the concrete mortar corresponds to that assumed in the preparation of the theoretical curves. When the air-entraining agent is added to the batch at the mixer it is not too difficult to produce any desired air content under a given set of conditions.

5. It is not known whether this method of design may be applicable for concrete mixes containing cements with interground air-entraining agents. It seems possible that the theoretical curves could be prepared from basic data on the cement without the interground agent if such cements could be obtained from the manufacturer. However, it would not be possible to have positive control over the amount of air entrained in the mix.

6. Tests on a series of mixes prepared in the laboratory according to the suggested method of design indicate that the method is sound and that the factor of safety provided need be no greater than that used in the design of standard portland-cement concrete, provided the air content of the concrete is subjected to adequate field control.

Acknowledgment:

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APPENDIX

SYNOPSIS OF THE MORTAR-VOIDS DESIGN PROCEDURE

The mortar-voids design procedure is based on the following main principles:

1. That a definite quantitative relationship exists between the magnitude of the voids in the concrete in place (water and air voids) and the compressive strength of the concrete, the quality and quantity of the cement and the quality and nature of the aggregate remaining the same but the gradation of the aggregate varying and other conditions remaining similar. (This relationship was determined by Talbot and Richart (1) on the basis of tests of hundreds of specimens and presented in the form of a compressive strength *versus* cement-space ratio curve.)
2. If the amount of the water and air voids in the mix of mortar to be used in making the concrete is known, the voids in the resulting concrete may be calculated, and the corresponding cement-space ratio may be used as an index of the strength of the concrete.
3. It is assumed that sufficient mortar is used to completely fill the voids in the coarse aggregate so that the mortar voids will be a measure of the voids in the concrete.

The composition of a unit volume of freshly made concrete may be expressed by the equation $a + b + c + v = 1$. The notations used in the above equation and in the following discussion were suggested by Talbot and Richart and have the following meanings:

a = absolute volume of fine aggregate in a unit volume of freshly made concrete.
b = absolute volume of coarse aggregate in a unit volume of freshly made concrete.
c = absolute volume of cement in a unit volume of freshly made concrete.
v = volume of voids in a unit volume of freshly made concrete, in which are included both air and water voids.
w = volume of water voids in a unit volume of freshly made concrete.

For a mortar the composition may be expressed by the equation $a_m + c_m + v_m = 1$ in which the letters represent the unit volumes of fine aggregate, cement and voids in a unit volume of freshly made mortar. If a mortar of known composition is mixed with a known volume of coarse aggregate the composition of a unit volume of concrete which results may be expressed by the equation $M + b = 1$ in which M represents the volume of the mortar, thus $M = 1 - b$. It follows that $a = a_m(1 - b)$ and $c = c_m(1 - b)$, etc.

The cement-space ratio as defined by Talbot and Richart is equal to the volume of the cement in the cement paste, or the quantity $c/(v + c)$. Assuming that the voids in the coarse aggregate are completely filled with mortar $c/(v + c)$ is equivalent to $c_m/(v_m + c_m)$.

The experimental basis of the mortar-voids design involves the preparation of a series of mortar mixes with a given ratio of fine aggregate to cement (a/c) and with varying amounts of water (w_m). The unit volume of each mix is determined and a curve of volume *versus* water content is plotted. The water content other than zero which produces the mortar with the least volume is designated as the basic water content (BWC).

Theoretically, this mortar could be mixed with coarse aggregate in order to produce the densest possible concrete. Practically, such a concrete would be too dry and unworkable to place unless excessive quantities of mortar were used. Therefore, it is necessary to multiply the basic water content by a factor in order to produce concrete of the desired workability. For example, if a concrete mix contains 10 per cent more water than the basic water content of the mortar used in the mix, it is said to have a relative water content (RWC) of 1.10.

In order to carry out the design, it is necessary to perform several sets of mortar-voids tests using different a/c ratios covering the range ordinarily used in concrete work. On the basis of these tests a final series of curves is then prepared in which the values of v_m, c_m, w_m and $c/(v + c)$ are plotted against a/c for basic water content and for the various relative water contents which have been found satisfactory for a given type of work. The value of b is selected on the basis of experience. The value of $c/(v + c)$ is determined by the desired strength, and for given values of RWC and b, it in turn determines the required values of a, c, v, and w.

DISCUSSION

Mr. Delmar L. Bloem[1] (*presented in written form*).—As pointed out by the author, the inclusion of air as an ingredient in concrete has introduced complications into well-established design procedures. The paper presents a usable direct approach for taking air into account in one of these procedures, namely, the mortar-voids method. This discussion presents a method of design for concrete containing entrained air which can be adapted to any proportioning procedure applicable to normal concrete. Provision is made for maximum use of information gained from experience with concrete not containing air.

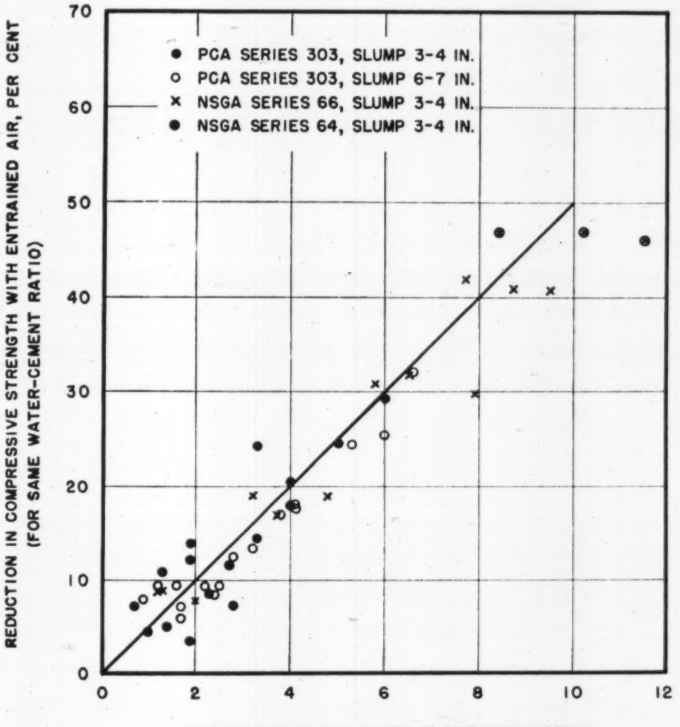

Fig. 8.—Reduction in Compressive Strength with Entrainment of Air when Water-Cement Ratio is Maintained Constant.

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[1] Assistant Director of Engineering, National Sand and Gravel Association and National Ready Mixed Concrete Association, Washington, D. C.

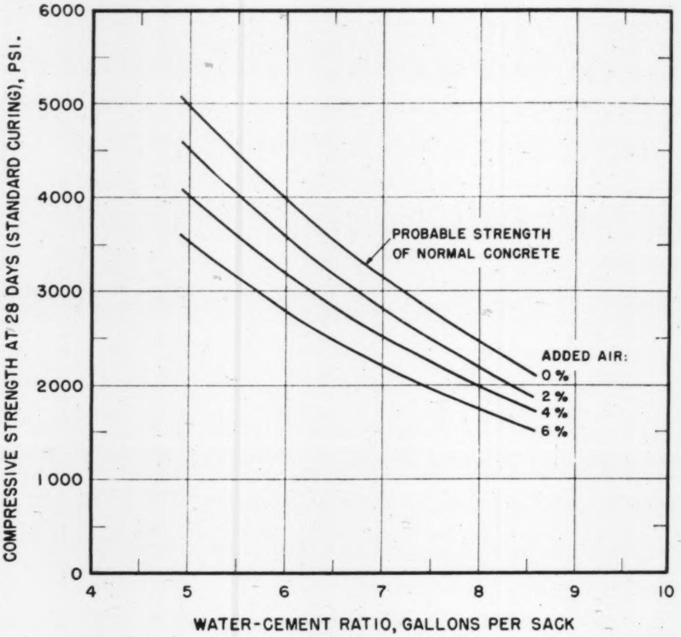

Fig. 9—Probable Compressive Strength for Different Water-Cement Ratios.

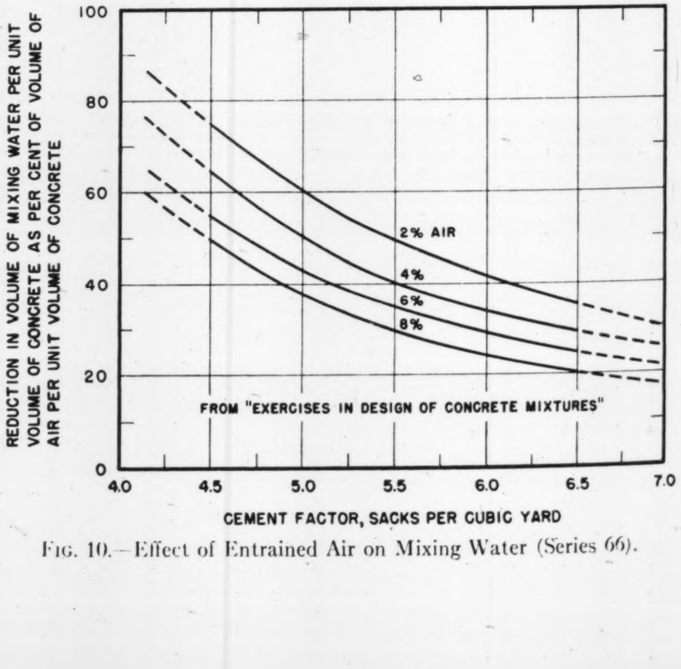

Fig. 10.—Effect of Entrained Air on Mixing Water (Series 66).

The accompanying Fig. 8 shows a relationship which has been developed between compressive strength and air content of concrete using data from the laboratories of the Portland Cement Assn. and the National Ready Mixed Concrete Assn. Here reductions in compressive strength resulting from air entrainment have been expressed as percentages of the strength of normal cement concrete *having the same water-cement ratio.* Actually for given proportions, the reduction in strength is considerably less than indicated, if the consistency is maintained the same, since the entrainment of air reduces the amount of water required. Nevertheless, the relationship provides a useful tool for designing air-entraining concrete by providing the basis for constructing a family of water-cement ratio-strength curves for various air contents as shown in the accompanying Fig. 9, based on established water-cement ratio relationships.

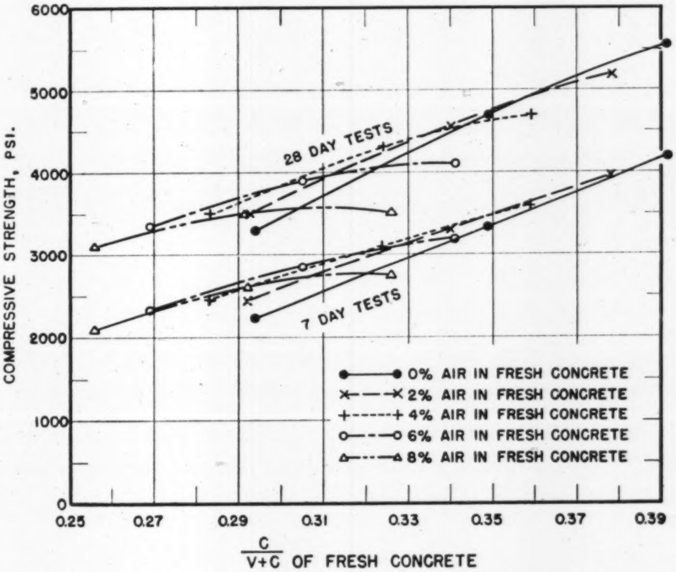

FIG. 11.—Relationship Between $c/(v + c)$ and Strength for Various Air Contents (Series 66).

Figure 10 shows the effect of air entrainment on water requirements of concrete based on data from an investigation carried out by the Association at the University of Maryland. It is believed that these data are sufficiently representative to be of general value. Reductions in quantity of water to produce a given slump have been expressed as percentages of the volume of entrained air. The use of these curves in conjunction with those shown in Fig. 9 permits the determination of the quantities of water and cement per unit volume of concrete. The completion of the design consists merely of selecting the relative quantities of fine and coarse aggregates required to occupy the remainder of the unit volume of concrete. This may be done by direct selection of the quantity of coarse aggregate as is done in the mortar-voids method or by an application of some other procedure involving the fineness modulus or b/b_o.

Tests in our laboratory have shown this method of proportioning air-entraining concrete to be quite rapid and to provide results of an accuracy comparing favorably with those obtained in designing normal cement concrete mixtures.

Comments on one or two points in the paper under discussion might be of interest. The author's design method is based on the assumption that the relationship between strength and cement-space ratio is the same regardless of whether the voids are entirely filled with water or filled partially with water and partially with air. Data from tests made by the Association at the University of Maryland, shown in Fig. 11, suggest that this assumption is quite accurate in the range of fairly rich concrete with which the author is chiefly concerned. It will be noted, however, that for leaner concrete the cement-space ratio - strength curves deviate more and more from the curve for normal cement concrete as the air content increases. These data suggest, therefore, that the author's assumption may lead to appreciable errors in the design of leaner mixes.

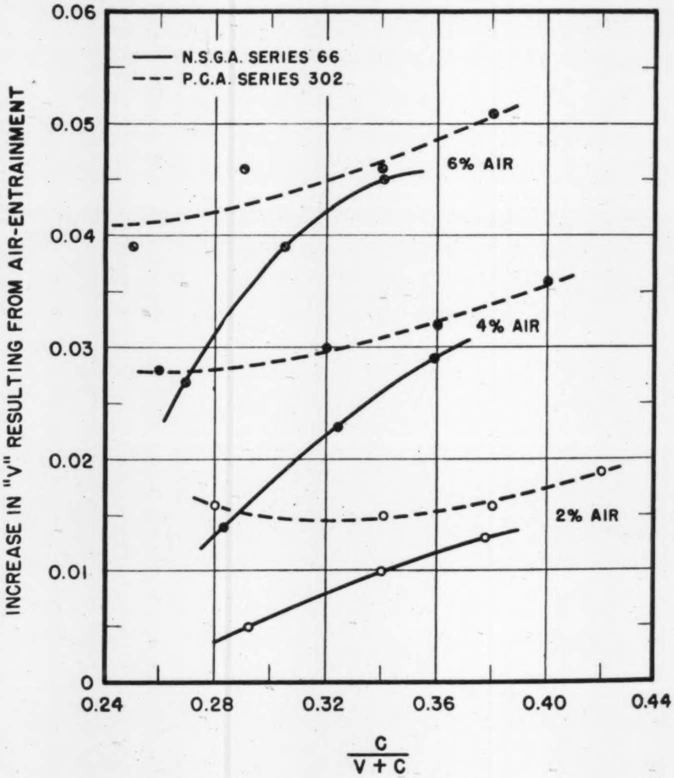

FIG. 12.—Relationship Between Cement-Space Ratio and Increase in Void Content of Concrete Resulting from Air-Entrainment.

Figure 12 suggests a possible means of correcting for air entrainment directly applicable to the mortar voids method of design. Here increases in volume of voids v resulting from air entrainment have been plotted against cement-space ratio. Both the increase in air voids and the reduction in water requirement resulting from air entrainment have been taken into account. Discrepancies between the curves from the two different laboratories may be attributable to different design procedures; in tests made by us, sand content was reduced as air content increased while in the Portland Cement Assn. tests the percentage of sand was maintained constant for all air contents for any given cement factor. The use of this family of curves will permit the design of air-entraining concrete without the necessity of replotting the mortar-voids design curves. The cement-space ratio required to produce the desired strength is selected and the value for v corresponding to this ratio and the desired consistency is determined using the mortar-voids curve for normal cement concrete. This value for v is then increased by the amount indicated in Fig. 12 and the new value for c determined from the known $c/(v + c)$ ratio. The quantity of water w is determined by subtracting the known percentage of air p from the new value of v. The quantity of coarse aggregate b is selected as described by the author and the quantity of sand a is determined by subtracting the sum of $c + b + v$ from 1.

MR. T. H. THORNBURN (*author's closure*).—The comments made by Mr. Bloem and his presentation of an alternate method of design are appreciated by the author. The data presented in Fig. 10 should be a particularly valuable aid in determining the water requirement to produce a given consistency.

With regard to the validity of the author's method of design for the leaner mixes, it is pointed out in the summary that the linear relationship between compressive strength and cement-space ratio was found to hold true within the range of strengths commonly used for pavement concrete, that is, rich mixes. The original relationship as determined by Talbot and Richart was expressed as a curve which had less of a slope for low values of $c/(v + c)$ than for high values. Recent tests made of concrete containing entrained air in the student laboratory at the University of Illinois[2] indicate that the shape of the compressive strength *versus* cement-space ratio curve for air-entrained concrete is approximately the same as that derived by Talbot and Richart for normal portland-cement concrete when the full range of useful concrete mixes is considered.

The data presented in Fig. 12 may represent a valid means of simplifying the suggested mortar-voids procedure, but the discrepancy between the two series of tests indicates that more evidence is needed. Unless such curves are generally applicable it would seem preferable to use the theoretical mortar-voids curves which are simply prepared once the experimental curves have been obtained.

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[2] E. E. Bauer, "Plain Concrete," third Edition, McGraw-Hill Book Co., New York, N. Y., pp. 124–125 (1949).

A WETTING-AND-DRYING TEST FOR PREDICTING CEMENT-AGGREGATE REACTION*

By C. H. Scholer[1]

Synopsis

This paper presents a method of determining the probability of a cement-aggregate reaction in any mixture of cement, fine aggregate, and coarse aggregate. The test essentially consists of subjecting specimens of concrete, approximately 3 by 4 by 16-in. to exposure of alternate drying at a raised temperature and wetting immersed in water at room temperature, with one cycle being completed in 24 hr.

For the extremely rapid reactions that may be secured with unusually high-alkali cement and reactive aggregates, it is much faster than the commonly accepted mortar bar test in a sealed container. The test is much more sensitive in that many combinations which do not show reaction under the commonly accepted mortar bar test will show abnormal expansion in the wetting-and-drying test.

Whether or not all of these expansions are directly the result of cement-aggregate reaction may be questioned, but it is believed that the test is highly significant and that where appreciable expansions occur under this test, there is considerable danger of serious reaction in such concrete combinations. The test is peculiarly valuable in that it may be used with coarse aggregate combinations and also because it shows the significant effect which various coarse aggregates may have upon the so-called cement-aggregate reaction. Some of the data indicate that the commonly accepted alkali limitations may not be very highly significant, and probably other elements than alkali alone are potent factors in determining the extent of the cement-aggregate reaction.

The wetting-and-drying test to determine cement-aggregate compatibility was probably first used by Mr. W. E. Gibson in 1932 (**1**).[2] This test was the outcome of an investigation of so-called "map-cracking" that was developing on certain Kansas concrete pavements and bridges. An extensive survey of the condition of pavements and structures was made at that time, and it was observed that the difficulty was confined to certain aggregate sources and was most frequently associated with certain cements. Mr. Gibson reported in his paper before the Highway Research Board the results secured by the wetting-and-drying test, which was the only method of exposure used in that investigation that gave results which correlated with observed field exposure.

Since 1942, the test has been further developed and used rather extensively at Kansas State College in connection with a cooperative investigation carried on by the Engineering Experiment Station of the College with the Portland Cement Assn. In recent years, several other laboratories have built equipment designed to embody the same general principles of exposure to moisture and temperature change.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] Professor of Applied Mechanics, Kansas State College, Manhattan, Kans.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 948.

This paper briefly describes the test as conducted at Kansas State College, and presents enough results to indicate some of the possibilities of the test.

METHOD OF TEST

The test provides for exposing saturated specimens of concrete to a drying condition at 130 F. for 8 hr. followed by immersion in water at an initial temperature of 70 to 80 F. for 16 hr. The process is repeated 6 days each week, the specimens remaining immersed over Sunday. The specimens are transferred from oven to tank and returned to the oven by manual methods. The oven in which the drying occurs (Fig. 1) is of wood construction, lined with Celotex, and heated by steam radiators in the bottom of the oven. Celotex baffles directly over the radiators prevent radiant heat from reaching the specimens directly, and a mild draft of air through the oven maintains a low relative humidity. Temperatures are controlled by means of Minneapolis-Honeywell Controllers, and air circulation is controlled manually by varying the size of openings at the bottom of the oven.

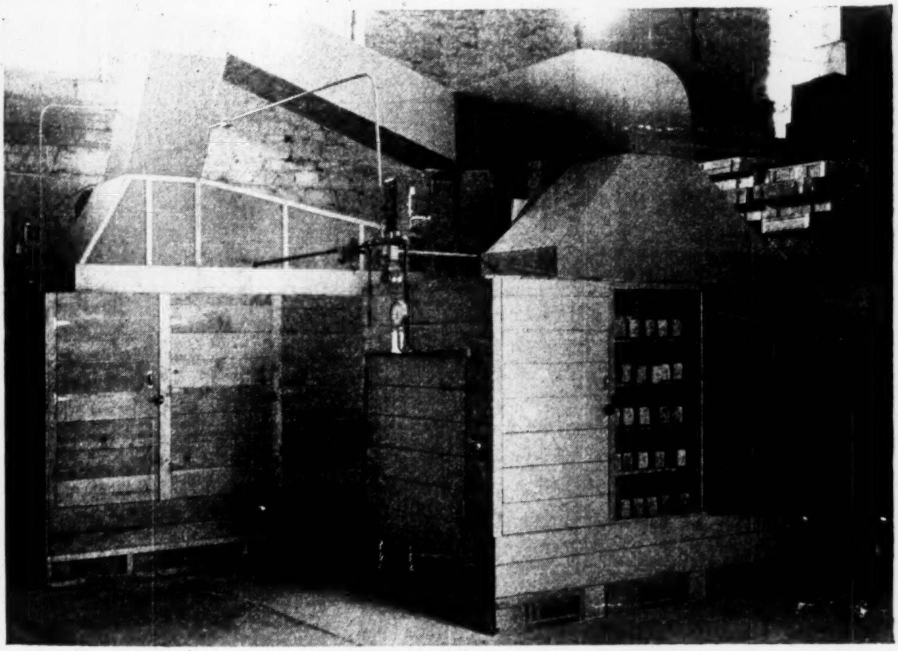

FIG. 1.—Drying Ovens for Wetting-and-Drying Test.

Evaporation and temperature rise are not very rapid. Several hours are required to bring the internal temperature of the specimen to 126 F., about the maximum reached. The evaporation loss in 8 hr. is about 40 g. per specimen.

The specimens are prisms 3 by 4 by 16 in. and weigh about 16 lb.

Other temperatures from 120 to 160 F. have been tried, but it is believed that the temperature of 130 F. is best adapted to the purpose. Lower temperatures have been found to retard the rate of development of the deterioration, and higher temperatures have been found to cause abnormal expansions with combinations of materials that have good service records. Field studies also indicate that temperatures over 130 F. are very seldom experienced in natural exposure (2).

Data are not available to show the effect of variations in the rate of drying, but it is believed that this should not be too rapid and that forced draft and dehydration of the air by chemical means should be avoided.

MECHANISM OF FAILURE

The cause of failure through excessive expansion, cracking, and loss of strength is not entirely understood. It is not caused by shock due to sudden immersion of the hot specimen in cold water. Somewhat similar results are produced in concrete specimens by keeping them immersed and rapidly changing the temperature of the water through a similar temperature range (3).

It is believed that a combination of moisture and temperature change frequently repeated is conducive to the development of distress in any nonhomogeneous absorptive material because:

1. Chemical action and resulting crystal growth will be accelerated.
2. Any weakness of bond between the aggregate and paste will tend to develop failure.

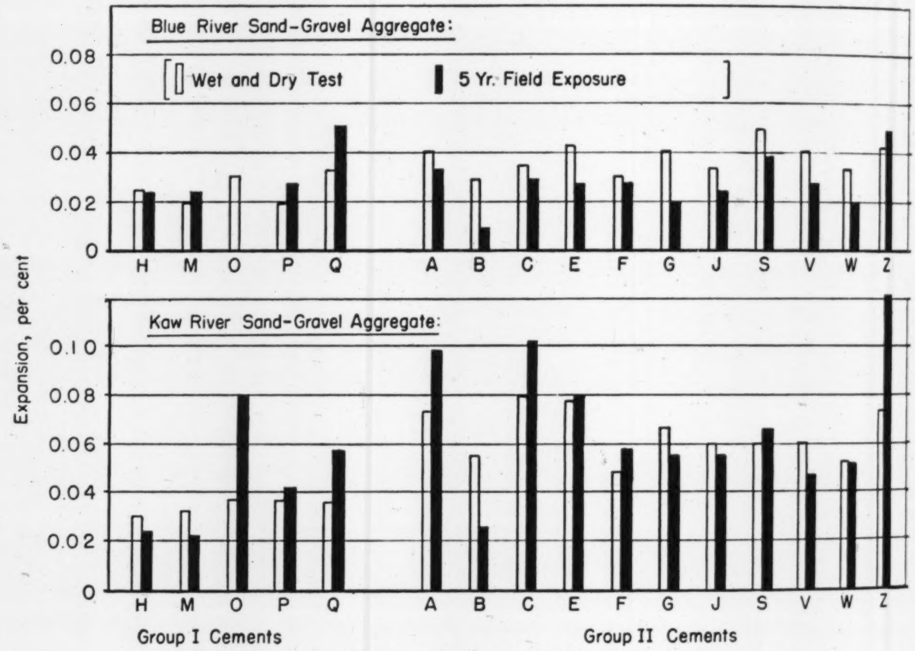

FIG. 2.—Comparing Results of Accelerated Test with Field Exposure.

Concrete made with the cements of Groups I and II were made with Kaw River and Blue River sand-gravel. The results of the wetting-and-drying test are here compared with five years of field exposure

3. Any lack of thermal compatibility will be accentuated.

4. After the first failure of bond between paste and aggregate, whether caused by adverse reaction between cement and aggregate or by overstressing due to thermal incompatibility, "jacking action" would tend to develop increasing expansion with succeeding differential volume changes, due to combinations of temperature and moisture changes.

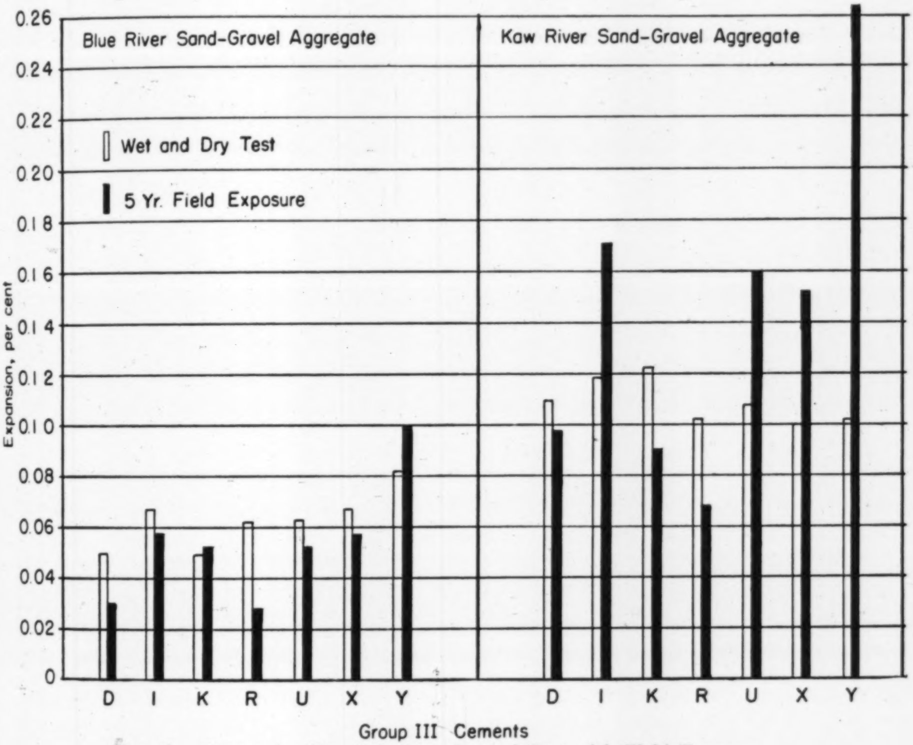

FIG. 3.—Comparing Results of Accelerated Test with Field Exposure.

Concrete made with the cements of Group III were made with Kaw River and Blue River sand gravel. The results of the wetting-and-drying test are here compared with five years of field exposure.

CORRELATION WITH FIELD EXPOSURE

To date, considerable data are available for comparison of the accelerated test with field exposure, from which it would appear that the method shows rather satisfactory correlation with field exposure.

Figures 2 and 3 show the expansion of concrete specimens during 285 cycles of the wetting-and-drying test compared to the expansion of companion specimens during 5 yr. of field exposure. Two different aggregates were used in these specimens; Kaw River sand-gravel which has a poor service record, and Blue River sand-gravel which has a good service record. Each aggregate was used in combination with 24 different cements in 3 by 4 by 16-in. concrete beams. Chemical analyses of the cements used in this series are shown in Table I.

The data in Figs. 2 and 3 are arranged in three groups on the basis of the per cent expansion in the wetting-and-drying test of the beams made with the Kaw River sand-gravel aggregate. Group I includes those cements which produced but little expansion in the test (0.04 per cent or less); group II includes cements producing moderate expansion (0.05 to 0.08 per cent); group III includes those producing 0.1 per cent expansion or more at the age of one year (285 cycles).

TABLE I.—CHEMICAL ANALYSIS OF CEMENTS.

Cement	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Loss on Ignition	K_2O	Na_2O	Na_2O equivalent of Total Alkali	Free lime
					GROUP I						
H	21.54	5.94	2.41	65.57	0.86	1.82	1.46	0.44	0.27	0.56	1.12
M	22.39	4.49	3.08	65.68	1.34	1.64	1.36	0.19	0.05	0.18	1.21
O	21.88	5.09	3.42	65.07	1.79	1.51	0.59	0.45	0.20	0.50	0.31
P	21.59	5.26	3.00	65.40	0.89	2.09	1.39	0.59	0.17	0.56	1.95
Q	20.77	6.58	3.19	65.47	0.85	1.96	0.54	0.31	0.14	0.34	Trace
					GROUP II						
A	20.67	6.37	3.10	63.47	3.07	1.79	0.82	0.42	0.28	0.56	0.06
B	20.38	5.47	3.10	64.18	2.07	1.96	1.99	0.53	0.26	0.61	1.39
C	19.65	6.23	2.71	65.04	2.61	1.90	1.31	0.45	0.32	0.62	1.50
E	20.49	5.73	3.65	64.12	2.49	1.70	1.15	0.41	0.21	0.48	0.58
F	21.94	5.72	2.52	65.25	1.30	1.35	1.37	0.37	0.22	0.46	1.42
G	20.59	7.10	2.65	63.78	2.70	1.69	1.00	0.54	0.23	0.59	0.17
J[a]	20.54	6.53	3.17	65.08	1.48	1.67	1.82	0.52	0.19	0.53	2.77
S	22.04	4.34	3.02	64.26	3.27	1.65	1.12	0.44	0.21	0.50	1.23
V	22.11	6.00	1.97	63.89	2.09	2.22	1.35	0.63	0.19	0.60	0.72
W	22.10	4.56	3.05	63.42	3.32	1.86	0.85	0.53	0.22	0.57	0.80
Z	20.85	6.15	2.73	64.38	3.20	1.49	0.66	0.51	0.10	0.44	Trace
					GROUP III						
D	21.28	5.57	3.44	63.72	3.72	1.69	0.83	0.50	0.26	0.59	0.42
I	21.96	5.87	2.35	63.76	2.90	1.64	0.82	0.38	0.34	0.59	0.96
K	22.04	5.15	3.04	62.90	2.98	1.73	1.33	1.16	0.07	0.83	0.58
R	20.64	4.27	2.89	63.04	5.68	1.58	1.48	0.66	0.21	0.64	0.41
U[a]	20.96	6.42	2.03	63.82	3.51	1.83	1.55	0.78	0.16	0.67	0.49
X	21.22	6.28	3.02	62.55	3.51	1.67	0.91	0.54	0.20	0.56	0.23
Y	21.27	5.40	2.48	64.08	2.55	1.97	0.79	1.03	0.19	0.87	1.26

[a] Mn_2O_3—Trace in all cements. Chloroform soluble—All below 0.006 per cent except cements J and U = 0.012 per cent.

In Figs. 2 and 3 the expansions of the specimens subjected to the wetting-and-drying test are shown by the open bars and the expansions during 5 yr. field exposure by the solid bars. The data shown are the average values for three specimens. In the field, the 3 by 4 by 16-in. concrete beams were exposed to the weather lying on the ground with a 4-in. face horizontal. Due to the fact that these small specimens were lying on the ground during the winter, they were subjected to unusually severe freezing-and-thawing exposure. It is probable that some of the expansion of these specimens with outdoor storage is due to this type of weathering. The expansion resulting from the freezing and thawing of these specimens would partially obscure the expansions resulting from a cement-aggregate reaction. Regardless of the effect of freezing and thawing, it is believed that the correlation of laboratory results with field exposure is excellent. Almost without exception, specimens made with the Kaw River aggregate show more expansion in both the laboratory test and in the field than those made with the same cement and Blue River aggregate.

At the end of 5 yr. outdoor exposure, only one of the concretes made with the Kaw River aggregate and the cements of group I have shown excessive expansion. All of the concretes made with the Kaw River aggregates and the cements of group III have shown excessive expansion.

In some of our earlier studies for certain combinations, 24 by 24 by 6-in. slabs were placed in outdoor exposure together with the 3 by 4 by 16-in. beams. Observations on the larger sized specimens have apparently shown results that are more consistent with the expansion obtained in the laboratory test. For the past 3 yr., a different type of field exposure specimen has been used. This specimen is shown in Fig. 4. Comparative data for this type of specimen are as yet not available. Freezing failures have occurred with some of the 3 by 4 by 16-in. beams in which the companion block illustrated in Fig. 4 has shown no distress.

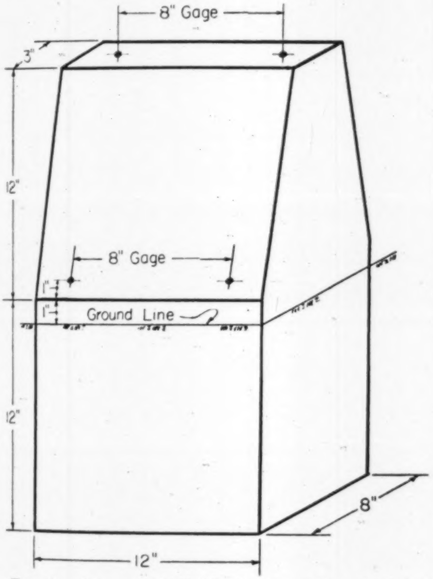

FIG. 4.—Suggested Field Exposure Specimen.

Duplicate specimens were also exposed to moist room storage at 70 F. for 1 yr. and to continuous warm moist storage in closed containers at 130 F. for 1 yr. In all instances, the expansion was negligible, less than 0.03 per cent for moist room storage at 70 F. and less than 0.04 per cent for warm moist storage.

Mortar bar specimens (1 by 1 by 11-in.) showed negligible expansion during 1 yr. storage in sealed containers at 70 F.

Forty years of field experience have shown but little adverse cement-aggregate reaction when Blue River sand-gravel is used as aggregate while Kaw River sand-gravel has an unsatisfactory record with many cements. It will be noted that only one cement of group III produced excessive expansion in the field with Blue River aggregate and that this expansion was indicated by the wetting-and-drying test.

As might be expected, the concretes made of group II cement have shown inconsistencies when Kaw River aggregate is used. Only four combinations with Kaw River aggregate have shown excessive expansion in the field and this was predicted by the wetting-and-drying test which showed over 0.07 per cent expansion at 1 yr. for these combinations. It is significant to note that cement Z, which shows the highest expansion in the field with Kaw River aggregate, has the lowest Na_2O equivalent (0.44 per cent) of any cement in group II.

It is not believed that Kaw River aggregate concretes in this test have shown a typical alkali-aggregate reaction. The mortar bars in the sealed containers did not develop significant expansion, and the concrete beams in warm moist storage showed no significant expansion.

It is believed that other characteristics of the aggregate or the cement or of the combination contributed to this reaction. Probably the use of a very high-alkali cement (1.2 per cent or more) might produce some reaction with Kaw River aggregate. Mr. T. E. Stanton of the California Division of Highways has found that Kaw River sand reacts mildly with high-alkali cements.

The method of test does, however, rapidly develop expansion in concretes made with alkali reactive aggregates and high-alkali cements. Mielenz and Witte (4) report that this type of test (wetting and drying), as developed in the laboratories of the U. S. Bureau of Reclamation, accelerates the alkali-aggregate reaction.

Concrete beams made with a cement having an alkali content of 0.99 sodium equivalent and Blue River sand-gravel made active by the addition of 5 per cent of siliceous magnesium limestone showed an expansion at 60 days of 0.198 per cent in the wetting-and-drying test, while the warm moist storage at 130 F. showed an expansion of 0.148 per cent. It is believed the test method is of unusual value for many aggregate and cement combinations where incompatibility is at a low level or borderline state of acceptability.

It is the author's opinion that too little attention has been given to the importance of coarse aggregate in a concrete and its effect upon the cement-aggregate reaction. Studies at Kansas State College (5) and the result of field observations show that certain coarse aggregates definitely inhibit the deterioration. This method of test and the size of specimen used in the test make it possible to study the effect of all of the constituents of the concrete mixture.

CONCLUSIONS

In conclusion, the author would like to point out several significant facts about this method of test which makes it of unusual value as a means of studying cement-aggregate reactions or incompatibility of the constituents of concrete.

1. It makes it possible to study the effects of all of the constituents of concrete; the cement, the fine aggregate, the coarse aggregate, and any additions or treatments that might be introduced.
2. It introduces no unusual handling or exposure procedures. The temperatures and humidities used are well within the range of natural exposure.
3. The method may readily be made automatic or semi-automatic in its operation. Several such devices have already been put into operation at other laboratories.
4. All concrete tests of this type should be paralleled by concrete specimens placed in the field for outside exposure. This is of the utmost importance.
5. Specimens for outside exposure should be larger than the 3 by 4 by 16-in. beams. Field experience indicates that a larger specimen is more resistant to freezing and thawing and, consequently, less likely to cause confusion in the interpretation of the type of failure which may occur. A specimen like that shown in Fig. 4 is recommended.
6. The effect of cement-aggregate reaction can best be measured by expansion of the test specimen. Change in sonic modulus has not been found satisfactory for measuring this type of deterioration.

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(2) W. J. Arndt, "Temperature Changes and Duration of High and Low Temperatures in a Concrete Pavement," *Proceedings*, Highway Research Board, Vol. 23, p. 273 (1943).

(3) E. R. Dawley, "Alternate Heating and Cooling of Mortar," *Journal*, Am. Concrete Inst., Vol. 7, No. 5, May–June, 1936, p. 609.

(4) Richard C. Mielenz, and Leslie P. Witte, "Tests Used by the Bureau of Reclamation for Identifying Reactive Concrete Aggregates," *Proceedings*, Am. Soc. Testing Mats., Vol. 48, p. 1071, (1948).

(5) C. H. Scholer, and W. E. Gibson, "Effect of Various Coarse Aggregates Upon the Cement-Aggregate Reaction," *Journal*, Am. Concrete Inst., Vol. 19, No. 10, June, 1948, p. 1009.

DISCUSSION

MR. T. E. STANTON[1] (*presented in written form*).—Mr. Scholer describes "a method of determining the probability of a cement-aggregate reaction in any mixture of cement, fine aggregate and coarse aggregate," the test essentially consisting of subjecting specimens of concrete approximately 3 by 4 by 16 in. to exposure of alternate drying at a raised temperature and wetting immersed in water at room temperature. He contends that "for the extremely rapid reactions that may be secured with unusually high-alkali cement and reactive aggregates, it is much faster than the commonly accepted mortar bar test in a sealed container."

Nowhere in his paper does Mr. Scholer present comparative test data substantiating the above contention.

In tests conducted by the Materials and Research Department of the California Division of Highways with high-alkali cement - reactive aggregate combinations, excessive expansions have developed in two weeks or less when stored in sealed containers at 100 to 110 F.

The reactive fine aggregate from the Santa Clara River, Ventura County commercial deposits at Saticoy, Montalvo and Piru always develop excessive expansion in two to four weeks in the sealed container test at 100 to 110 F.

Mr. Scholer describes results in an alternate wetting-and-drying test which were duplicated by us over ten years ago in our search for an appropriate test procedure to duplicate the cement-aggregate reaction observed in constructed works.

At that time, through alternate wetting and drying tests we developed excessive expansion and ultimate failure of concrete specimens in which the coarse aggregate consisted of a non-reactive shale. The results of the above tests are illustrated in the accompanying Fig. 5.

It is conceivable that with certain size test specimens an accelerated expansion may be developed through some alternate wetting and drying procedure which is the result of both a cement-aggregate reaction and a normal increase in volume of the aggregate which has no relation to the cement-aggregate reaction phenomena.

Hundreds of tests by this department have demonstrated that no form of wetting-and-drying test can be depended upon to disclose a potential adverse cement-aggregate reaction in tests on relatively small sized specimens, and it is very doubtful if any part of an accelerated expansion developed from alternate wetting and drying which may have been due to a cement-aggregate reaction is as rapid or as great as would have developed had the sealed container procedure at 100 to 110 F. been followed.

MR. D. O. WOOLF.[2]—Mr. Scholer has mentioned the thing that I think is of interest in this paper which is in addition to the presentation of a method of test.

If consideration is given to the service record of the several pieces of concrete which were used in these tests, it will be found that there are three cements with which specimens were made and good results were obtained, and there are four cements with which specimens were made and exceptionally poor results were obtained.

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[1] Materials and Research Engineer, California Division of Highways, Sacramento, Calif.

[2] Senior Materials Engineer, Public Roads Administration, Washington, D. C.

This is on the basis of service record, not of the wetting-and-drying cycle. If a comparison is made between the three cements with good results and the four cements with poor results, the only significant difference which can be found in the chemical analyses of the seven cements is the magnesia content.

For quite a long time persons have been talking about magnesia in cement. We have instituted the autoclave soundness test to be sure that cement does not contain excessive amounts of free magnesia or free lime. In spite of that, there are still occasional references to magnesia content and its effect on the durability of concrete made with the cement.

The three cements which give the best results in this series of weathering tests are cements H, M, and B. They have an average magnesia content of 1.42 per cent. The four cements which give poor results are I, U, X, and Y. They have an average magnesia content of 3.12 per cent.

The magnesia is all within the specification limits, but it certainly does appear to indicate that there must be some difference between the cements which have a smaller amount of magnesia and the ones which have the larger amount. I can find no other significant difference between these seven cements. I think that in these tests, Mr. Scholer did mention that magnesia was possibly significant. He didn't elaborate on it but I think it is worth while elaborating on, and that these tests are of sufficient moment to cause us to re-examine chemical

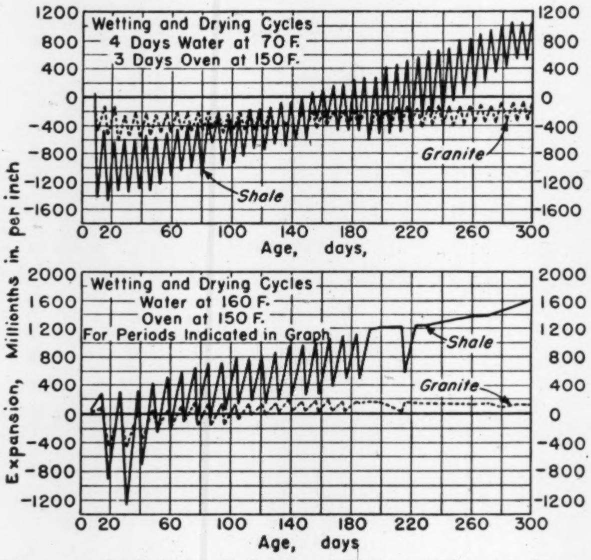

FIG. 5.—Tests to Compare the Relative Influence of Shale and Granite Coarse Aggregate on the Volume Change of Concrete When Subjected to Alternate Wetting and Drying Cycles at the Temperatures Noted.

Test Specimens 2 by 2 by 11½-in. Bars (Effective Gage Length 10 in).

analyses of cements which have given good and bad results in service. If greater consideration should be given to magnesia we might be able to find one of the several missing factors that may still exist in our studies of cement and concrete.

Mr. Blanks[3] of the Bureau of Reclamation published a paper in the *Proceedings* of the American Society of Civil Engineers in which he discussed the behavior of portland-cement concrete. He said among other things that there may be a number of different considerations, all of which added together spell success or failure of concrete, anyone of which by itself would not be of any essential consequence. Possibly if we add alkali to magnesia to some other things we will some day find out why some concretes hold together and some others go to pieces.

MR. BRYANT MATHER.[4]—The paper presented by Mr. Scholer represents a milestone of concrete research. We have here a non-freezing weathering test described as being applicable for predicting the durability of any concrete, representing any cement-aggregate combination, recommended by a man who is perhaps more familiar with intricacies and complexities of testing concrete for durability than anyone else.

I feel, however, that as presented it is a research procedure and not yet a routine test for concrete materials.

I would like to inquire of Mr. Scholer whether, in his opinion, it would perhaps be possible to simplify and further accelerate the test?

The paper, as presented, states that it is of utmost importance that in parallel with specimens tested in the laboratory there shall also be specimens exposed in the field. It is indicated that a number of years are required to gain the information from the field specimens.

I suggest that a routine test should, at least ultimately, be able to stand on its own merits and not require correlative data from natural exposure.

Secondly, it appears that the results are not available from the laboratory test in many cases until a year after the specimens are made. For routine testing of materials proposed for specific construction, that period of time is seldom available.

I wonder if the test can be accelerated by modification of exposure conditions. Mr. Scholer has said the test introduces no unusual conditions of handling and emphasizes that the temperatures and humidities of the exposure used are within the range of those which occur in nature. However there must be some unusual conditions about the test for it to be accelerated at all. At least the results are obtainable sooner than they are in nature. If, then, it is accelerated already, perhaps it might be accelerated further. Perhaps cooling to a lower temperature could be used. Lower temperatures are, of course, known in nature. Perhaps the rate of temperature change could be increased, and perhaps a cycle involving a combination of heating and wetting opposed to cooling and drying might be used to give a maximum volume change per cycle.

I should like to know what Mr. Scholer's feelings are as to the possibility of eliminating the field specimens and accelerating the test for routine use by modification of the exposure conditions.

MR. C. H. SCHOLER (*author's closure*).—Referring to Mr. Mather's discussion, I agree in principle with his suggestion that this procedure is a research procedure and not yet a routine test. I say this for two reasons:

1. In the present state of our knowledge of durability tests, whether for

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[3] R. F. Blanks, "Modern Concepts Applied to Concrete Aggregate," *Proceedings*, Am. Soc. Civil Engrs., Vol. 75, No. 4, April, 1949, p. 441.

[4] Engineer, Concrete Research Div., Waterways Experiment Station, Corps of Engineers, U. S. Army, Jackson, Miss.

freezing and thawing or for determination of adverse cement-aggregate reactions, all methods are in the research phase. As long as we know so little about the significance of the tests which we are performing, they should be looked upon primarily as research and investigation even though we may be, at the same time, compelled to accept the results as our most significant guide for the routine acceptance or rejection of a material.

2. As implied by Mr. Mather, the test takes too long for its completion. We are making every attempt to find some faster method of securing this information, with some rather promising results. I should like to point out, however, that the more rapidly we accelerate this test, the more subject to question will be the results which we secure.

For both of the above reasons I still insist that it is of the utmost importance that we have parallel field specimens under normal exposure which may later be compared with the results of our accelerated test. As suggested by Mr. Mather, ultimately, we hope to be able to develop a test which will really stand upon its own merits. Merely to fail to make parallel field specimens does not indicate that the test has reached such a degree of standardization. A typical example, for instance, is the autoclave test for soundness of cement. The author has never seen any field data to indicate that this test is really a measure of soundness of the resulting concrete. There is every reason to believe that cement with an expansion many times the limits provided in our specifications may produce acceptable results. The author has a series of field specimens of concrete that have been in the field for over eleven years. These specimens were made up with cements having expansions from slight shrinkage to over ten per cent expansion. To date, all concretes are performing alike.

As stated in the paper, the test procedure does not involve unusual ranges of temperatures or humidities. It does, however, provide for an unusually rapid change in these temperatures and humidities. As to what extent this rate of change might be increased without introducing complications, only a research covering many years will be able to determine.

Referring again to Mr. Mather's question as to whether or not it would be possible to eliminate the field specimens, the author wishes to point out that the field specimens are unnecessary if one is willing to accept the results of the accelerated test as final. As stated previously, it is the author's belief that our present state of knowledge is so limited in matters of concrete durability that it would be a very wise procedure to, every year, place many field specimens duplicating our accelerated tests for later observation in the hope that some day we would be able to develop more significant tests and test limits for concrete durability.

Mr. Stanton points out that the author included no data in his original paper showing that the proposed wetting-and-drying test for predicting cement-aggregate reaction was faster than the standard mortar-bar test for predicting such reaction. This is true, and perhaps the author was in error in not including these data. The results were all negative, and as a result, the data were omitted. Standard mortar-bar tests were made on the 23 cements with Blue River and Kaw River aggregate, shown in Figs. 2 and 3. After two years of exposure the expansions were all nominal: 0.01 to 0.02 per cent. Mr. Stanton states that many hundreds of tests in his laboratory indicate that the wetting-and-drying test showed no results with their aggregate. The tests described by Mr. Stanton, although they are wetting-and-drying tests, in no wise duplicate the procedure outlined in this paper. In one instance he uses 4 days in water at 70 F. and 3 days in the oven at 150 F. This procedure provides for a very severe drying situation at a temperature such as to produce very unsatisfactory results. In another instance they were placed in water at 150 F. and in an oven at 150 F., in each instance for several days at a time. Again these temperatures are excessive, and the drying cycles very severe. It is the author's belief that both the size and shape of the test specimen as well as the temperature changes to which it is exposed must be very closely controlled in order to have parallel tests. Mr. Stanton states that he has made hundreds of tests which have demonstrated that no form of wetting-and-drying test can be depended upon to disclose a potential adverse cement-aggregate reaction regardless of the size of the specimen. The example which he submits, however, in no wise duplicates the test suggested by the author and if he did make tests which approximately duplicate those described by the author, it is unfortunate that he did not use these examples in presenting this discussion.

We have conducted a very limited series of tests as to the effect of size of the test specimen using 1 by 1-in. mortar bars, 3 by 4 by 16-in. prisms, and 6-in. cubes. At the end of 125 cycles of wetting and drying the expansion shown by the 1 by 1-in bar was negligible. The 3 by 4-in. prism showed an expansion of 0.10 per cent, and the 6-in. cube showed an expansion of 0.30 per cent.

Mr. Woolf's comments on the significance of magnesia in the cement would appear to be pertinent by the data submitted. However, if the magnesia is a significant element one would wonder why the reaction with Blue River was not similarly affected, as indicated with the Kaw River aggregate. It will be noted that for both groups and 1 and 2 cements, the Blue River aggregate has developed but little expansion after five years of field exposure, whereas the Kaw River aggregate has developed critical expansion in several instances. It should further be pointed out that cement R, in group III, the cement which has the highest magnesia content of any of the cements, tested, shows the lowest field expansion with both Blue River and Kaw River aggregate. It is not believed that the expansion can be explained by magnesia content alone. It is very likely that a combination of two or more adverse actions is in many instances responsible for the deterioration observed.

CHEMICAL REACTIONS OF INDIANA AGGREGATE IN DISINTEGRATION OF CONCRETE*

BY FLOYD O. SLATE[1]

SYNOPSIS

This study was made to determine whether or not chemical reactions of aggregates have played an important part in the disintegration of certain concrete pavements in Indiana. Previous field work had shown a positive correlation between certain types of disintegration and the type of coarse aggregate used in the mix. In the present study, two general approaches were used: First, a series of widely accepted, empirical tests for chemical reactivity between cement and aggregate were performed (expansion bar tests, alkali-immersion pat tests, and alkali-reactivity "bomb" tests) on most of the major types of Indiana's limestone aggregates and some of the gravels—both good and bad. Second, several specific tests were made on the suspected reactants (chemical analysis of aggregate, petrographic analysis of aggregate, petrographic analysis of disintegrated concrete, macroscopic examination of disintegrated concrete, and others). Considerable information was collected concerning chemical and mineralogical composition of several of Indiana's sedimentary rocks. For the aggregates studied, no appreciable chemical reaction was found which would cause disintegration of concrete.

Disintegration of certain concrete pavements, as evidenced by complete failure, by blowups, and by map cracking, has been found to be an important problem in Indiana (**7**).[2] An effort has been made by the Joint Highway Research Project, Purdue University, to determine the cause of this disintegration. The study was divided into two phases, chemical and physical (**5**); this paper is a report of the chemical study.

Extensive field surveys established a positive correlation between disintegration and type of coarse aggregate used; no other factors were found to correlate with disintegration (**7**). In various other parts of the country, a similar correlation was found, and the disintegration was attributed to expansion resulting from chemical reaction between certain constituents of the aggregate and alkalies in the cement. An extensive literature has been published on this alkali-aggregate reaction. Considerable previous work has been done on disintegration of concrete with reference to soundness, freezing-and-thawing durability, improper proportioning and placing, poor materials (cement and aggregate), thermal expansion, and other items.

The results obtained from this study are applicable to all aggregates of similar chemical and mineralogical composition, and are not limited to rocks from Indiana. Similar materials are found in Ohio,

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[1] Research Chemist, Joint Highway Research Project, Purdue University, West Lafayette, Ind.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 961.

Tennessee, Kentucky, Illinois, Missouri, Iowa, Wisconsin, and Michigan, and perhaps in other parts of the country. The scope of such problems is indicated in a recent paper by Woods (8). Gravel limestones as well as quarry limestones are applicable.

After a survey of this previous work, it was decided to use the following approach to determine whether or not chemical reactions involving coarse aggregates were primarily responsible for disintegration of Indiana's concrete pavements:

TABLE I.—INDIANA AGGREGATES TESTED FOR CHEMICAL REACTIVITY IN CONCRETE.

Laboratory[a]	Source[a]	Type	Geologic Formations and Period[b]	Field Performance[c]
No. 210	No. 9-1S	Dolomitic limestone	Kokomo—Silurian	Bad
No. 267	No. 67-2S	Limestone	St. Genevieve—Miss.	Good
No. 267-I	No. 67-2S	Cherty limestone	St. Genevieve—Miss.	...
No. 270-C	No. 35-2S	Chert	Chert from Liston Creek—Silurian	Bad
No. 270-L	No. 35-2S	Dolomitic limestone	Ls. from Liston Creek—Silurian	Good (?)
No. 272	No. 9-1S	Limestone	Kenneth—Devonian	...
No. 277-A	No. 34-2S	Cherty limestone	Kenneth—Devonian	...
No. 277-B	No. 34-2S	Limestone	Kokomo—Silurian	Bad
No. 277-C	No. 34-2S	Dolomitic limestone	Kokomo—Silurian	Bad
No. 282-B	No. 3-1S	Limestone	Beechwood—Devonian	Bad
No. 282-D, H	No. 3-1S	Dolomitic limestone	Jeffersonville—Devonian	
No. 283	No. 40-3S	Dolomitic limestone	Jeffersonville—Devonian	Bad
No. 284	No. 47-2S	Limestone	St. Louis (?)—Miss.	Bad
No. 287	No. 9-1S	Dolomitic limestone	Kokomo—Silurian	Bad
No. 288	No. 35-2S	Chert	Liston Creek—Silurian	Bad
No. 288-LS	No. 35-2S	Dolomitic limestone	Liston Creek—Silurian	...
No. 290	No 67-1S	Limestone	St. Genevieve—Miss.	Good
No. 291-B_2	No. 27-2S	Limestone	Liston Creek—Silurian	...
No. 292-D_1, E_2	No. 35-3S	Dolomitic limestone	Liston Creek—Silurian	...
No. 293-D	No. 90-1S	Dolomitic limestone	Reef in Liston Cr.—Silurian	Good (?)
No. 294-A_3, A_4, B_3, B_4, C_2, C_3	No. 9-2S	Dolomitic limestone	Kokomo—Silurian	...
No. 298-A	No 71-1S	Limestone	Beechwood—Jeffersonville—Devonian	Good
No. 299-A_1	No. 40-3S	Limestone	Beechwood—Devonian	Bad
No. 299-A_2	No. 40-3S	Limestone	Jeffersonville—Devonian	
No. 299-A_3	No. 40-3S	Dolomitic limestone	Jeffersonville—Devonian	
No. 2003-A_3, A_5, A_6	No. 59-1S	Limestone	St. Genevieve—Miss.	Good
No. 2003-A_8	No. 59-1S	Limestone	St. Genevieve—Miss.	...
No. 2004-C_7	No. 3-1S	Dolomitic limestone	Jeffersonville—Devonian	...
No. 2005	No. 23-4S	Chert	Chert ledge in Borden—Miss.	...
No. 2007	No. 1-1S	Dolomite	Reef in Liston Creek (?)—Silurian	...
No. 2010-A_2, A_5	No. 67-8S	Limestone	St. Genevieve—Miss.	...
No. 2020	No. 70-6S	Dolomitic limestone	Geneva—Devonian	...
No. 2021-5	No. 34-5S	Dolomitic limestone	Kokomo—Silurian	...
No. 2023-3	No. 59-1S	Limestone	St. Genevieve—Miss.	Good
No. 2024-1, 2	No. 13-4S	Limestone	Glen Dean—Miss.	...
No. 2025-A_2, 1, 3	No. 47-10S	Limestone	St. Genevieve—Miss.	...
No. 2027-2, 3, 4, 5	No. 60-1S	Limestone	St. Genevieve—Miss.	Good
No. 2028-1, 2, 3, 4, 5	No. 53-2S	Limestone	Harrodsburg—Miss.	...
No. 2029-1, 3	No. 40-6S	Limestone	Laurel—Silurian	...
No. 2030-A_4, B_4	No. 3-1S	Dolomitic limestone	Jeffersonville—Devonian	...
No. 2031-1, 2, 3, 4	No. 34-5S	Limestone	Kokomo—Silurian	...
No 2031-5, 6	No. 34-5S	Dolomitic limestone	Kokomo—Silurian	...
No. 51-1S	No. 51-1S	Limestone	?—Miss.	Good
No. 59-1S-3	No. 59-1S	Limestone	St. Genevieve—Miss.	Good
No. 47-1S	No. 47-1S	Limestone	?—Miss.	...
No. 47-2S-S	No. 47-2S	Limestone	St. Louis—Miss.	Bad
No. 47-2S-H	No. 47-2S	Limestone	St. Louis—Miss.	Bad
No. 85-1S	No. 85-1S	Dolomite	Liston Creek or Mississinewa—Silurian	...
Ann-A	...	Limestone	Jeffersonville—Devonian (?)	Bad
Ann-B, C	...	Dolomitic limestone	Jeffersonville—Devonian (?)	Bad
	No. 79-1	Sand	Glacial sand	Good
	No. 79-1G	Gravel	Glacial gravel	Fair
	No. 82-1G	Gravel	Ohio River Gravel	Bad
	No. 84-1G	Gravel	Wabash River Gravel	Poor
Stanton	...	Siliceous magnesian limestone from Calif.		...
Ottawa	...	Sand	...	...

[a] Laboratory numbers usually represent ledges of stone, while source numbers usually represent quarries. Complete descriptions of samples and of source locations are on file at the Joint Highway Research Project, Purdue University.

[b] Information furnished by D. W. Lewis, Purdue University, and based mostly on records of the Indiana Department of Conservation, Division of Geology.

[c] Ratings are based on performance records of pavements made with the aggregate in question and, as a result, usually refer to entire quarries, as represented by source numbers and not laboratory sample numbers.

1. Perform the widely-accepted, empirical tests for detection of alkali-aggregate reaction (expansion of mortar bars, alkali-immersion pat tests, and "bomb" tests for alkali reactivity of aggregates).
2. Make chemical analyses of the major types of aggregates.
3. Make petrographic analyses of the major types of aggregates.
4. Make petrographic studies of disintegrated concrete for evidence of chemical action.
5. Make macroscopic examinations of disintegrated concrete for evidence of chemical action.
6. Make miscellaneous tests.

EXPERIMENTAL WORK

Materials:

Table I lists the aggregates studied.

Three portland cements were used. Cement No. 302 had an alkali equivalent of 1.14 per cent sodium oxide; No. 303, 0.75 per cent; and No. 304, 0.40 per cent.

Procedures:

Chemical Analyses.— Standard methods, usually those of H. S. Washington (6), were used. The single precipitation urea method for calcium was substituted for the usual double precipitation. The insoluble residue was determined by placing 10 g. of material passing a No. 100 sieve in 200 ml. of water, adding hydrochloric acid to the color change of methyl red then 10 ml. excess, heating to incipient boiling, filtering, and weighing. The clay content was estimated by determining the iron oxide group in the insoluble residue, determining the iron content of the iron oxide group, subtracting ferric oxide from total iron oxide group to obtain alumina, and multiplying the alumina content of the insoluble residue by a factor 4 (average content of alumina in clay likely to be present). This procedure (an estimation, not a determination) was based on the assumptions that all the clay would remain with the insoluble residue, that all the alumina in the insoluble residue was present in clay, and that the factor 4 was valid.

Petrographic Analyses.—Thin sections of aggregates (and in some cases of good and of disintegrated concrete containing these aggregates) were prepared and examined for presence of constitutents recognized as reactive with alkalies in cement and, in the sections of concrete, for any evidence of detrimental chemical reaction at the interface of cement and aggregate.

Expansion Bars.—This test, evolved from Stanton's work (1), is widely accepted as an empirical method of determining presence or absence of detrimental alkali-reactive aggregate. In the tests reported here, 1 by 1 by 10 in. mortar bars were stored vertically over water in a sealed container at 80 ± 5 F. and were measured periodically for changes in length.

Bomb Tests.—The procedure followed that outlined by Mielenz, Greene, and Benton (2) involving reaction of powdered aggregate with 1 *N* sodium hydroxide for 24 hr. at 80 ± 1 C. in a sealed container followed by measurement of reduction of alkalinity and solution of silica. A "Parr" bomb was used in place of the one recommended, and sample sizes were reduced correspondingly.

Pat Tests (4).—Pieces of aggregate were used to make 2 in. mortar cubes which were sawed in half, then stored for two months under the surface of an alkaline solution. The faces of the aggregate particles were examined for evidence of reaction, including irradiation by ultraviolet light in a darkroom.

Macroscopic Examination of Concrete.—During field trips, pieces of concrete were broken from many different pavements and examined for beads or pockets of reaction products from alkali-aggregate reaction and for any other signs of chemical action involving the aggregates.

TABLE II.—CHEMICAL COMPOSITION OF INDIANA AGGREGATES, PER CENT.[a]

	Sample No. 210	Sample No. 267	Sample No. 267 I	Sample No. 270-C	Sample No. 270-L	Sample No. 272	Sample No. 277-A	Sample No. 277-B	Sample No. 277-C	Sample No. 282-D	Sample No. 282-H	Sample No 283
SiO_2	3.00	1.11	10.5	65.5	4.95	4.81	60.07	0.86	4.7	1.2	0.56	0.57
R_2O_3[b]	1.3	1.80	2.2	2.27	1.8	0.51	1.3	0.83	4.0	0.67	2.90	4.20
Fe_2O_3	0.61	0.27	0.32	0.78	0.58	1.07	0.65	0.15	1.40	0.50	0.20	0.62
FeO	0.09	0.09	0.07	0.05	0.06	0.00	0.00	0.00	0.06	0.05	0.06	0.05
MgO	19.4	0.34	0.44	5.98	19.9	0.32	0.15	0.37	17.8	18.42	18.07	17.1
CaO	29.9	54.64	48.2	10.6	28.6	51.7	20.86	54.9	29.8	33.60	32.1	33.2
Na_2O	0.08	0.09	0.00	0.01	0.00	0.07	0.04	0.05	0.10	0.00	0.13	0.19
K_2O	0.22	0.00	0.18	0.14	0.30	0.13	0.00	0.02	0.18	0.00	0.10	0.09
Uncombined water 110 C.	0.13	0.05	0.09	0.09	0.05	0.03	0.06	0.06	0.04	0.05	0.04	0.03
Combined water 110 C.	0.09	0.16	0.35	0.36	0.15	0.13	0.34	0.07	0.17	0.05	0.08	0.07
P_2O_5	0.21	0.13	0.11	0.09	0.12	0.09	0.16	0.20	0.24	0.13	0.08	0.16
CO_2	44.53	41.53	37.7	14.71	43.3	41.5	16.99	42.7	42.1	44.95	46.1	44.2
Organic Carbon	0.02	0.19	0.06	0.00	0.00	0.01	0.00	0.11	0.00	0.08	0.05	0.00
SO_3 (Soluble)	0.06	0.09	0.06	0.02	0.03	0.03	0.01	0.06	0.13	0.11	0.07	0.10
S^c	0.00	0.09	0.05	0.11	0.14	0.08	0.06	0.06	0.12	0.11	0.09	0.12
Subtotal	99.54	100.58	100.33	100.71	99.98	100.48	100.69	100.44	100.84	99.92	100.63	100.70
$0 \approx S^d(-)$	0.00	0.03	0.02	0.04	0.05	0.03	0.02	0.02	0.04	0.04	0.03	0.05
Total	99.54	100.55	100.31	100.67	99.93	100.45	100.67	100.42	100.80	99.88	100.60	100.65
Insoluble residue	4.94	1.63	n.d.	68.75	7.05	14.60	61.61	1.74	8.4	2.05	2.57	3.52
Clay (estimated)	3.2	1.0	n.d.	6.5	4.2	3.0	1.1	1.0	10.4	0.8	2.2	1.4

	Sample No. 284	Sample No. 293-D	Sample No. 2004-C7	Sample No. 2005	Sample No. 2007	Sample No. 47-2S-H	Sample No. 47-2S-S	Sample No. 51-1S	Sample No. 59-1S-3	Sample No. 2031-3	Sample No. 2031-4	Sample No. 2031-6
SiO_2	3.94	3.95	2.5	90.6	1.94	0.31	0.68	0.74	0.01	n.d.	n.d.	n.d.
R_2O_3[b]	4.14	3.0	2.1	5.37	2.61	1.89	1.6	2.56	2.18	n.d.	n.d.	n.d.
Fe_2O_3	0.23	0.07	0.11	0.32	0.14	0.06	0.07	0.14	0.08	n.d.	n.d.	n d.
FeO	0.03	0.05	0.07	0.08	0.02	0.01	0.02	0.03	0.02	n.d.	n.d.	n.d.
MgO	3.77	20.02	15.4	0.16	20.24	0.68	0.72	0.56	0.50	n.d.	n.d.	n.d.
CaO	48.33	29.0	35.7	0.41	30.07	54.77	54.38	54.54	54.79	n.d.	n.d.	n.d.
Na_2O	0.09	0.00	0.02	0.00	0.00	0.04	0.02	0.00	n.d.	n d.	n.d.	n.d.
K_2O	0.13	0.03	0.02	0.00	0.05	0.04	0.10	0.00	n.d.	n.d.	n.d.	n.d.
Uncombined water 110 C.	0.14	0.05	0.03	0.11	0.04	0.04	0.04	0.07	0.03	n.d.	n.d.	n.d.
Combined water 110 C.	0.40	0.50	0.10	0.80	0.32	0.02	0.30	0.06	0.00	n.d.	n.d.	n.d.
P_2O_5	0.06	0.23	0.10	0.14	0.10	0.16	0.26	0.13	0.11	n.d.	n.d.	n.d.
CO_2	38.9	43.73	43.83	2.10	44.6	41.5	48.87	41.02	41.71	n.d.	n.d.	n.d.
Organic Carbon	0.20	0.04	0.03	0.00	0.00	0.41	0.18	0.10	0.16	n.d.	n.d.	n.d.
SO_3 (Soluble)	0.25	0.09	0.26	0.05	0.21	0.24	0.07	0.06	0.12	n.d.	n.d.	n.d.
S^c	0.19	0.15	0.28	0.00	0.08	0.03	0.04	0.04	0.04	n.d.	n.d.	n.d.
Subtotal	100.80	100.91	100.55	100.14	100.42	100.20	100.35	100.05	99.75			
$0 \approx S^d\ (-)$	0.07	0.06	0.10	0.00	0.03	0.01	0.01	0.01	0.01			
Total	100.73	100.85	100.45	100.14	100.39	100.19	100.34	100.04	99.74			
Insoluble Residue	5.64	3.98	3.04	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	5.70	1.13	8.59
Clay (Estimated)	2.6	3.3	1.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	3.1	0.3	5.2

[a] n.d. = no determination.
[b] Oxides of Al, Ti, Zr, Cr, V, and rare earths.
[c] Total sulfur minus sulfur in SO_3.
[d] Assuming sulfur present in pyrite, factor = 0.375.

DATA

Chemical Analyses:

The results of chemical analyses are listed in Table II. In general, the dolomitic limestones had poorer field performance and were more porous and more absorptive (5) than the calcitic limestones. This may be associated with mode of formation; it is deserving of further study. All the rocks analyzed, including cherts, contained only small amounts of combined water (retained when heated beyond 110 C.). This indicates lack of hydrated compounds (hydrated silica compounds may react with alkalies in cement).

Petrographic Analyses of Aggregates:

There was a notable absence of opal and other minerals usually associated with alkali-aggregate reaction (3) (except for chalcedony in sample No. 270 C). A good correlation was obtained between quantitative estimations of mineral content from petrographic analysis, and mineral composition calculated from chemical analysis. Petrographic studies can furnish much-needed information about pore structure of aggregates.

Sample No. 210.—A fine-grained dolomitic limestone of porous texture containing approximately 1 per cent quartz sand. The carbonate is in small rhombs and rhombic grains averaging about 0.008 mm. in diameter. A few rhombs are larger, up to 0.06 mm. diameter. The rock shows bedding marked by alternate layers of fine and coarse carbonate. The porous structure follows the coarser layers.

Sample No. 267.—A medium-grained fossiliferous (crinoid) limestone. The fossil fragments have been rounded to grains averaging 0.06 mm. diameter which are set closely in a mat of finer fossil fragments. The larger fragments have recrystallized to single grains of calcite with obliteration of most of the organic structure. Impurities: about 4 per cent sand (mostly quartz) and a little microcline. The sand is a little finer in grain than the lime fragments. No clay or other impurities could be found.

Sample No. 270 C.—A chert composed of organic silica ranging from subcrystalline to chalcedony to fine-grained quartz. The silica shows small organic remains. Dolomite rhombs are abundant through the silica but are very unevenly distributed, ranging from 10 per cent to 50 per cent in different parts of the sample. There is a trace of kaolin clay.

Sample No. 270 L.—A fine-grained dolomite containing a trace of fine quartz sand. No other impurities were found. The texture is compact. The dolomite grains are mostly automorphic or hemimorphic rhombs averaging 0.015 mm. in diameter.

Sample No. 282 B.—A medium-grained recrystallized fossiliferous limestone. It is composed of fossil fragments of various sizes, up to 0.4 mm. diameter. Each fragment has recrystallized to a single grain of calcite with obliteration of most of the organic structure. Impurities: 6 per cent quartz sand of subangular form and rather uniform size averaging about 0.07 mm. diameter, a few fragments of collophane showing bony structure, less than 1 per cent kaolin clay.

Sample No. 282 D.—A very fine-grained porous dolomite. The carbonate is in hemimorphic rhombs averaging 0.01 mm. diameter Impurities: a little fine quartz sand, a few fragments of collophane showing bony structure, a trace of kaolin clay.

Sample No. 282 H.—A fine-grained dolomitic limestone showing bedding. The bedding is marked by alternate fine and coarse carbonate layers. The coarser layers carry from 1 per cent to 2 per cent quartz sand and are more porous than the finer-grained layers No trace of clay was found.

Sample No. 283.—A bedded, fine-grained dolomitic limestone. The bedding is marked by alternate fine and coarse layers. The coarser layers carry from 2 per cent to 4 per cent quartz sand and a little kaolin clay. A little hematite in earthy form and iron oxide stains were found associated with the clay. The porosity follows the coarser layers.

Sample No. 2031–3.—An extremely fine-grained limestone. It contains a trace of quartz. There are extensive deposits of bituminous material in small diffuse veinlets parallel to the plane of bedding. No fractures are evident. Another amorphous material (probably clay) is scattered throughout the mass in amounts of 2 per cent to 10 per cent.

Sample No. 2031–4.—An extremely fine-grained limestone. It contains very few pores of microscopic size and none of macroscopic size. There is a trace of quartz present. About 2 per cent to 5 per cent of clay plus bituminous material is present in fractures. These two materials appear to be closely associated and occur only in plate-like layers —they are not distributed evenly throughout the mass, even in part. The residue insoluble in hydrochloric acid consists of flat plates of amorphous material. This ledge of stone is variable in appearance. Three main types occur: (1) an evenly thinly bedded limestone of medium gray color, (2) an unevenly bedded limestone predominately dark gray in color, and (3) a very dark-gray limestone containing appreciable quantities of silica, and having few laminations. All are alike in having very few pores and in containing the clay and bitumen in definite veins.

Sample No. 2031–6.—An extremely fine-grained dolomitic limestone. It contains many microscopic pores; the mottled effect of the texture indicates the possibility of extensive pores of submicroscopic size. There are extensive deposits of a bituminous material in fractures parallel with the plane of bedding. There is 2 per cent to 10 per cent of another amorphous material (probably clay) partially concentrated in layers associated with the bituminous material and partially scattered throughout the mass. Inclusions (approximately 2 per cent) of highly altered minerals (probably remnants of organic remains) follow the bituminous layers. A trace of quartz is present.

Sample No. 85–1S.—A fine-grained, impure dolomite bed. It is composed of approximately 81 per cent dolomite, 12 per cent quartz, 5 per cent mica, and 2 per cent limonite. The dolomite is in minute rhombs. The quartz occurs as small sand grains. The mica occurs as shreds, sedimentary in origin. The limonite is an alteration product of pyrite. The rock is very fine grained and of loose porous structure. The sample has been altered by oxidation under surface conditions.

Sample No. Ann A.—A limestone of very irregular grain size. The calcite grains range in size from 0.24 mm. to 0.02 mm. in diameter. The grains show a slight rounding and are fitted together at random. There are a few rhombs, recrystallized, in the finer material that are probably dolomite. The organic structure of the calcite is barely discernible in some of the larger grains. Impurities: quartz sand, approximately 4 per cent; gypsum 2 per cent; collophane showing bony structure, trace; kaolin stained by iron oxides, trace. The texture is compact.

Sample No. Ann B.—A very fine-grained dolomitic limestone showing bedding of alternate fine and coarse layers. The coarser layers carry from 1 per cent to 3 per cent quartz sand and a little kaolin. A relict structure was observed of some prismatic mineral based on the coarser layers and projecting into the finer layers. The mineral has been replaced by granular calcite.

TABLE III.—MORTAR BAR EXPANSION TEST FOR ALKALI REACTIVITY OF CONCRETE AGGREGATES.[a]

Composition of Bars				Expansion, percentage of Bar Length		
Aggregate Tested	Percentage	Aggregate Filler	Cement	2 months	6 months	12 months
No. 79-1	100	...	302	0.003	0.007	0.012
No. 79-1	100	...	303	0.001	0.003	0.003
Ottawa	100	...	302	0.010	0.016	...
Ottawa	100	...	303	0.000	0.001	...
Stanton	5	79-1	302	...	0.141	0.148
Stanton	5	79-1	303	...	0.045	0.148
Stanton	5	Ottawa	302	...	0.025	0.038
Stanton	5	Ottawa	303	...	0.086	0.165
No. 210	10	Ottawa	302	0.005	0.009	...
No. 210	10	Ottawa	303	0.000	0.000	...
No. 210	5	79-1	302	0.001	0.006	0.010
No. 210	5	79-1	303	0.000	0.002	0.003
No. 267	10	Ottawa	302	0.001	0.005	...
No. 267	10	Ottawa	303	0.000	0.000	...
No. 267	5	79-1	302	0.000	0.005	0.010
No. 267	5	79-1	303	0.000	0.000	0.002
No. 270-C	5	79-1	302	0.013	0.018	0.022
No. 270-C	5	79-1	303	0.001	0.003	0.003
No. 283	5	79-1	302	0.009	0.005	0.012
No. 283	5	79-1	303	0.000	0.009	0.010
No. 284	5	79-1	302	0.001	0.008	0.011
No. 284	5	79-1	303	...	0.000	0.001
No. 293-D	5	79-1	302	0.006	0.014	0.016
No. 293-D	5	79-1	303	0.003	0.004	0.005
No. 302	10	Ottawa	302	0.000	0.005	...
No. 302	10	Ottawa	303	0.000	0.000	...
No. 2004-C7	5	79-1	302	0.013	0.018	0.023
No. 2004-C7	5	79-1	303	0.006	0.005	0.010
No. 2005	5	79-1	302	0.006	0.012	0.016
No. 2005	5	79-1	303	0.007	0.000	0.001
No. 2007	5	79-1	302	0.012	0.015	0.019
No. 2007	5	79-1	303	0.000	0.002	0.002
No. 79-1G	5	79-1	302	...	0.014	0.018
No. 79-1G	5	79-1	303	0.000	0.001	0.005
No. 82-1G[b]	5	79-1	302	0.009	0.012	0.024
No. 82-1G[b]	5	79-1	303	0.008	0.003	0.014
No. 82-1G[c]	5	79-1	302	0.012	0.011	0.012
No. 82-1G[c]	5	79-1	303	...	0.006	0.003
No. 84-1G[c]	5	79-1	302	0.011	0.014	0.018
No. 84-1G[c]	5	79-1	303	0.002	0.002	0.002

[a] Blanks and Meissner (1) say, "Aggregates which show no more than 0.02 per cent expansion after six months storage may be considered to be nonreactive, those which show expansions exceeding 0.04 per cent in this same period or earlier should be regarded with suspicion, and any giving expansions of 0.1 per cent should be considered definitely reactive" [when tested at 100 F.].

[b] All passing No. 4 sieve.

[c] All retained on No. 4 sieve.

Sample No. Ann C.—A fine-grained bedded dolomitic limestone with alternate fine and coarse layers. The section does not show relict prismatic structure. Impurities: a trace of kaolin clay; approximately 2 per cent quartz sand; a few large pyrite crystals altered to limonite, and iron oxide stains.

Petrographic Analysis of Disintegrated Concrete:

In no concrete examined was there any evidence of chemical reaction between aggregate and cement (for example, alteration of the aggregate near the interface).

TABLE IV.—BOMB TEST FOR ALKALI REACTIVITY OF CONCRETE AGGREGATES.[a]

Aggregate	Reduction in Alkalinity, millimoles per liter	Dissolved SiO_2, millimoles per liter	Number of Tests
Stanton	290	390	3
No 277-A	220	100	3
No. 277-B	130	7	1
No. 277-C	570	1	1
No. 282-D	530	1	7
No. 282-H	530	1	4
No. 283	520	1	4
No. 287	540	1	4
No. 288	250	290	5
No. 288-LS	480	4	3
No. 290	470	1	2
No. 291-B_2	430	140	1
No. 292-D	390	200	1
No. 292-E_2	500	4	1
No. 293-D	430	1	1
No. 294-A_3	540	1	1
No. 294-A_4	590	1	1
No. 294-B_3	510	1	1
No. 294-B_4	560	1	1
No. 294-C_2	450	0	2
No. 294-C_3	560	1	1
No. 298-A	300	1	1
No. 299-A_1	60	4	1
No. 299-A_2	520	1	1
No. 299-A_5	440	1	1
No. 2003-A_3	10	1	1
No. 2003-A_5	460	1	1
No. 2003-A_6	40	2	1
No. 2003-A_8	20	2	1
No 2010-A_2	430	1	2
No. 2010-A_5	350	1	1
No. 2021-5	480	1	1
No. 2023-3	340	2	2
No. 2024-1	440	1	1
No. 2024-2	110	2	2
No. 2025-1	80	3	1
No. 2025-3	130	4	1
No. 2025-A_2	10	4	2
No. 2027-2	400	1	1
No. 2027-3	90	4	2
No. 2027-4	200	3	2
No. 2027-5	130	1	2
No. 2028-1	530	1	1
No. 2028-2	290	1	1
No. 2028-3	60	1	1
No. 2028-4	200	2	1
No. 2028-5	330	1	1
No. 2029-1	400	1	1
No. 2029-3	490	1	1
No. 2030-B_4	460	1	1
No. 2031-1	80	4	2
No. 2031-2	100	1	1
No. 2031-4	70	2	2
No. 2031-5	550	1	1
No. 2080-2	270	1	1

[a] Mielenz, Greene, and Benton (2) say, "For quick estimation, aggregates characterized by a ratio of S_c/R_c greater than 1 may be considered deleterious." S_c = dissolved SiO_2, millimoles per liter; R_c = reduction in alkalinity, millimoles per liter.

Expansion Bar Test:

Results are given in Table III, indicating that not one of the Indiana aggregates studied is alkali reactive.

Bomb Test:

Results of the bomb test are given in Table IV, indicating that all Indiana aggregates tested, except those from the Liston Creek formation, are distinctly nonreactive with alkali. The Liston Creek formation represents a borderline case. The calcitic stones reduced alkalinity by formation of weakly basic calcium hydroxide, which is only partially neutralized by hydrochloric acid at the phenolphthalein end point. This effect was even stronger with dolomitic limestones, because magnesium hydroxide is an even weaker base. This using up of alkali might decrease release of silica.

Pat Tests:

Only the Stanton (California) aggregate showed any sign of reaction after two month's immersion in the alkaline solution. All the Indiana limestones and gravels tested (210, 267, 282 D, 282 H, 283, 284, 288, 293 D, 294, 2020, 2021, 79-1, 79-1G, and 82-1G) failed to react.

Macroscopic Examination:

No "gel" pockets or beads (products of alkali-aggregate reaction) were found in any concrete examined. Samples from many locations in Indiana, representing many aggregates sources, were examined.

DISCUSSION

This paper represents an attempt to find if chemical reactions were or were not to blame for concrete disintegration. The approach was to test, by a process of elimination, for presence of certain reactions. Since none were found, the paper may be termed "negative." However, this "negative" data is of value because of its interest to users and potential users of the aggregates, because it eliminates an entire field of consideration by researchers studying these materials, and because it adds to the store of knowledge about properties of rocks. There is always a possibility—surely remote—that detrimental reactions did occur and that the tests chosen were not adequate to discover these reactions. As a result, the principal conclusion was worded precisely "on the basis of the tests used."

The term "chemically reactive" as used in this paper refers to change in molecular composition of materials involved and does not apply to crystal and capillary pressures involved in freezing-and-thawing processes.

Not all aggregate sources in Indiana were sampled, and the entire group of tests was not run on all the sources that were sampled. Sampling procedure was a combination of the "grab" and the "channel-chipping" methods. It is believed that the materials studied are generally representative of Indiana quarry aggregates; however, it is possible that some untested aggregates may be chemically reactive in a detrimental manner in concrete.

CONCLUSIONS

1. On the basis of the tests used, none of the Indiana aggregates studied exhibit detrimental chemical reaction in concrete.

2. Chert from the Liston Creek formation, although classed as "nonreactive," should be viewed with suspicion in regard to alkali-aggregate reaction.

3. Bad field performance is shown by a greater percentage of dolomitic than of calcitic Indiana limestones. (This correlation is probably associated with porosity of the aggregate (5, 7)).

Acknowledgments:

This study was conducted in the Joint Highway Research Project, Purdue University, and partly financed by the Testing Laboratories of the State Highway Commission of Indiana. K. B. Woods, Associate Director of the Project, conceived the idea of this study and furnished assistance and encouragement throughout its course. Mrs. Barbara L. Horner performed most of the chemical analyses and part of the bomb tests. Mr. D. W. Lewis helped in various stages of the work.

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DISCUSSION

Mr. Bryant Mather.[1]—We have a study here which involves a variety of tests, two of which are petrographic. I think the correlation between petrographic work and chemical and performance test data is an extremely worthwhile and important project.

I have a few quibbles. I note that in the list of materials examined there are three cherts and two cherty limestones. Apparently all of the materials that were studied were not tested by all of the methods. However I find that the petrographic report on one of the cherts (sample No. 270 C) indicates that it contains chalcedony.

I should like to point out that it has been recognized by many investigators that chalcedony is one of the materials which is associated with deleterious chemical reaction. I do not have any desire to frighten anybody in Indiana. I do, however, believe it would be more proper to say that Indiana is free of concrete troubles related to chemical reactions not because of the absence of chemically undesirable constituents in its aggregates, but rather in spite of the fact that chalcedony is there.

I should also like to mention one point in connection with the data on mortar-bar expansions. It was my impression from the paper that the tests were, in almost every case, made on mortars in which only a small portion of the material under test was blended with a large portion of inert material. My understanding is that this approach is the one that will give maximum expansions when the material under test is a highly reactive aggregate. With an aggregate of only moderate chemical reactivity, such an approach frequently will mask such tendency to react as may exist, and most of the data which have been published and with which these presented here may be compared were made on mortar bars in which the entire aggregate was the material under test. I think that this point might be emphasized.

Mr. D. O. Woolf.[2]—This paper states that examinations were made of concrete which was in a distressed condition and that no evidence of chemical reaction between the aggregate and cement was found, as, for example, alteration of the aggregate near the interface.

I should like to have Mr. Slate describe how the concrete was sampled and what size specimens were taken, for this reason: In the work which we have done in trying to sample concrete to determine distress due to alkali aggregate reaction, we found it practically impossible to chip the surface of the concrete off and obtain definite information. The concrete near the surface or concrete which is badly cracked does not appear to contain the gel relics. They have been weathered out. If the sampling procedure consisted of removing a small chip near the surface and examining that, I believe a different picture would be obtained than if one were to examine a large block of concrete and reduce that by fracture to small pieces and examining those.

Mr. Harold Sweet.[3]—I should like to compliment Mr. Slate on a very clear and concise presentation of these interesting data. In view of the widespread concern over chemical reaction of aggregates in concrete, it is refreshing to receive this report wherein no evidence of chemical reaction was found. Some of these aggregates, acceptable by standard acceptance tests, are clearly shown by field performance to be unsuitable for concrete. It is clear that standard methods for specifying and testing physical properties of aggregate require close study and revision.

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[2] Senior Materials Engineer, Public Roads Administration, Washington, D. C.

[3] Assistant Professor of Civil Engineering, The University of Wyoming, Laramie, Wyo.

MR. F. O. SLATE (*author*).—In reply to Mr. Mather, a choice had to be made in the number of different tests to be run because of limitations of time and equipment. We chose the 5 per cent material to be studied, with 95 per cent filler, as the most widely used single test; we chose the 5 per cent realizing it would not be best for all materials. However, any material that is reactive will probably show appreciable expansion of a concentration of 5 per cent. And, in addition, we chose other independent tests on alkali reactivity, such as the pat test and the bomb test, considering that we would get most complete coverage by using various independent tests rather than spending most of our time on exhaustive tests of one kind only.

I do not claim that we do not get any chemical reaction. I state specifically that we do not get detrimental chemical reaction—that chemical reactions are not primarily responsible for the disintegration that is obtained.

(My error in omitting to call attention to the presence of chalcedony has been corrected in the published paper.)

In reply to Mr. Woolf, the field specimens were chipped from the edge of concrete pavements with a sledge hammer. They usually were three or four inches deep into the concrete and extended, whenever we could get such a sample, to the bottom of the pavement. They were 4 to 6 in. wide. These specimens were examined visually for appearance of gel or for gel remnants, which usually are not weathered completely away except in thin layers at the surface. We made several thin sections from each of most of the specimens—sometimes as many as ten for a specimen.

ENGINEERING PROPERTIES OF CORAL REEF MATERIALS*

By C. Martin Duke[1]

Synopsis

For engineering purposes the tropical calcareous earth materials derived from coral reefs may be classified as coral, limestone, and cascajo, with coral the ancestor of the other two. Using this classification, a basis is suggested for the systematization of our knowledge of the engineering properties of coral reef materials. Lack of such a basis heretofore has been the cause of much confusion among engineers.

The biologic and geologic aspects of coral reef formation are briefly summarized.

Results of tests on cascajo from Guam are presented. This important material exists plentifully on the older tropical islands. The test results, supported by experience, indicate excellent mechanical-, asphalt-, and cement-stabilization properties and fair concrete-making properties for properly selected materials.

The basic principles developed for design and construction with more conventional earth materials have been found to apply in practically full force to reef-derived materials.

A bibliography is given on origin and growth of coral reefs and on properties of reef-derived materials.

The engineering properties of the many useful natural materials derived from coral reefs have been the object of much study during the past few years. Our present engineering knowledge of these materials is built almost entirely on war and postwar construction experiences in the tropical Pacific and in the Carribean. We also have available as background a considerable literature on the geologic, biologic, and oceanographic aspects of coral reef formation and alteration. A bibliography of the principal engineering and geologic contributions of most immediate usefulness appears at the end of this paper.

During 1946–47, the author spent one year on Guam in connection with postwar Naval construction, where he directed investigations of the engineering properties of about forty reef-derived materials, and of the foundation characteristics of many more. This paper has been written with the two-fold objective of making the Guam investigations available to the profession and of suggesing a basis for engineering classification of coral-reef materials. The emphasis is on use of these materials in concrete, road, and runway work, though an attempt has been made to describe briefly the in-place characteristics of reef-derived materials in their important rôle as foundations of structures.

The tests described herein were performed under the cognizance of the Bureau of Yards and Docks, Rear

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

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Admiral J. J. Manning, CEC, USN, Chief of the Bureau, Captain E. L. Hansen, CEC, USN, Officer in Charge of Construction, Bureau of Yards and Docks Contracts, Marianas Area, and Mr. P. C. MacCallum, General Manager, Pacific Islands Engineers.

ORIGIN OF REEF MATERIALS

To develop a logical classification of coral-reef-derived materials, it is proper to consider first the natural processes involved in formation, emergence, and alteration of coral reefs. Accordingly, our current knowledge of these phenomena, which is far from complete, is briefly discussed below. Many of the scientific items discussed are controversial.

The general requirements for growth of coral reefs are (1) conditions favorable to the growth of lime-secreting reef-building organisms, and (2) favorable physiographic conditions of the shoreline.

The largest volume of the growing portion of most coral reefs is made up of accumulated calcareous secretions of coral polyps, which are invertebrate animals of the Anemone family. The calcium carbonate secreted by coral polyps is in the form of aragonite, a relatively weak and soluble mineral. The second largest contributors of volume, and probably the principal contributors of strength, are the secretions of nullipore algae, which are plants, mostly of the family Corallinaceae.[2] Practically all reef-building organisms obtain their food from the sea water. The calcium carbonate secreted by nullipore algae is in the form of calcite and some dolomite, both of which have greater strength and less solubility than the coral polyp secretions. Both of these organisms thrive in clear, circulating tropical sea water at depths up to about 130 ft. Their growth is inhibited by water temperature below about 67 F. (**3**, **12**).[3] In their newly-hatched or larval stage they are transported by ocean currents, and any solid non-shifting section of tropical coastline or shallow bottom with favorable water conditions is suitable for colonization by drifting organisms.

Additions to a reef are made on the shallower portions of its seaward face by building-up of coral and nullipore skeletons and other matter such as sand, shells, and volcanic sediments, and on the deeper portions by accumulation in a talus slope of fragments of reef battered loose by wave action. Additions are made on the top of a subsiding reef due to building up of skeletons, and on the shoreward or lagoon side by deposition of reef detritus and of detrital material supplied by erosion of the island (**11**). Measurements have indicated rates of coral growth of the order of one inch per year. This may in some cases approximate the rate of reef growth since the spaces between corals are filled with sand, shells, and sediments and are cemented with nullipores (**3**). The growth of reef-building organisms is discouraged locally by lack of food, which may be caused by stagnant sea water or by the dilution of sea water at mouths of streams; this fact plus the weathering action of the waves account in large degree for the formation of gaps and cavities in growing reefs.

A number of hypotheses have been advanced to explain the physiographic activities leading to the formation of modern and recent coral reefs. These hypotheses have been based on extensive observation, but the subject is still one of great controversy among geologists. Reefs have been thought by various investigators to have been formed (*a*) by vertical and lateral accumulation of coral and nullipore skeletons during gradual or intermittent subsidence of the coastline or ocean floor (1, 2); (*b*) by lateral accumulation on rising coastline (2) (this is not generally believed today); (*c*) by vertical accumulation on eroded submarine ledges following rise of the oceans after the "ice ages" (2) (this is complicated by elevation of islands due to mountain-building forces). A possible compromise has been offered by Stearns (10), who asserts applicability of hypotheses (*a*) and (*b*) to areas of the Pacific east and west, respectively, of the eastern edge of the Australasian platform, and of hypothesis (*c*) to reefs now living.

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[2] Some reefs have been formed predominantly of nullipore skeletons (**3**, **6**, **7**).

[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 975.

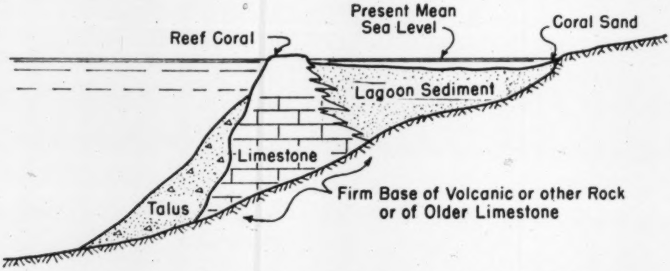

FIG. 1.—Schematic Cross-Section of a Coral Reef Formed During a Single Continuous Subsidence of the Coast Line.

It may be seen from the above discussion that the idealized "living" reef consists of a central cemented mass (often containing large interior and surface cavities) flanked by a talus slope to seaward, by lagoon deposits to landward, and by growing corals and nullipores on the top and upper seaward slope. It rests on a firm base which may be bedrock or an older reef. Such a reef is illustrated in cross-section in Fig. 1. The central mass, which is initially composed primarily of cemented skeletal remains, tends to be altered in various ways depending upon ambient geologic conditions. Most often it changes by gradual solution and recrystallization to limestone rock. From these living reefs there are obtained the geologically young materials of the tops and lagoons for use in construction work.

On Guam, and on others of the geologically older islands in whose development coral reefs played a significant part, the greatest volumes of coral reef materials readily available for use in concrete and in road construction are found on land. Also on these islands there are deposits of older reef materials often covered by recent sediments laid down in drowned valleys; these reef materials are often used as foundations of structures. The complicated geologic history of these older materials involves continuous or intermittent elevation or subsidence of the once-living reefs, complete with their talus, beach deposits, lagoon sediments, and surface and interior cavities. During periods of elevation and subsidence the actions of disintegration, decomposition, mountain building, erosion, and deposition are at work in altering the character of the reef materials; the weathering activities of the ocean, fresh water, vegetation, and wind are all effective (4, 5, 6, 9). The form, density, and purity of the older materials are therefore more variable than can be comprehended.

ENGINEERING CLASSIFICATION

An engineering classification of coral reef materials according to geologic age is presented in this paper, using the terms coral, limestone, and cascajo.

The recently-formed "coral" is normally the only reef material available on atolls, while larger islands fringed by reefs usually contain both recent and older reef materials in addition to volcanic and other rocks. The designation "coral" for geologically young materials is generally accepted, but this term is also commonly applied loosely to tropical calcareous earths of greater age, resulting in much confusion among engineers. It is recommended that two additional terms be used.

"Limestone" is the common name given continental deposits of relatively hard, pure rock formed by solution and subsequent recrystallization of calcium and magnesium carbonates. It is surely reasonable to apply the same name to the same rocks regardless of where found. "Limestone" will therefore be used in the following to designate the geologically older, structurally sounder, largely crystalline, reef-derived materials. Limestone usually makes up much of the central mass of older reefs.

A third class of coral reef material, usually of about the same age as limestone, is formed by processes different from those resulting in limestone and is found in nature in a variety of forms, always structurally inferior to limestone rock. This third class contains the lagoon sediments, the talus, and the incompletely altered and cemented skeletal remains of reef-building organisms, all of which have gone through the geologic changes described in the previous section; it also includes the detritus of elevated and subsequently-eroded limestone reefs and the products of decomposition of such reefs. The name assigned to this class of material is "cascajo." This term is in common use by natives and construction forces on Guam; it was adopted from the natives by military construction forces during the recent world war. The word is of Spanish origin, meaning "gravel," and is pronounced "kas-ka′-ho."

In Table I is given a suggested classification of coral reef materials using the above definitions and based on a survey of 35 pits and quarries on Guam, on Guam foundation experiences, and on a study of the literature. The three principal classifications are further subdivided into the classes of coral reef materials useful in construction. The table gives representative physical properties and approximate U.S. Public Roads Administration soil groups; the following detailed qualitative descriptions are keyed to Table I. Quantitative data on properties are given or referred to later.

TABLE I.—ENGINEERING CLASSIFICATION OF CORAL REEF MATERIALS.

Classification		Bulk Specific Gravity	Absorption, per-cent by weight	Approximate U. S. Public Roads Administration Group
Coral	Reef coral	1.7 to 2.2	5–20	A-2
	Lagoon coral	1.8 to 2.4	5–20	A-3
	Coral sand	2.3 to 2.5	3–7	A-3
Limestone	Limestone	2.6	1–3	...
	Limestone sand	2.6	1–3	A-3
Cascajo	Grade A	2.3 to 2.6	3	A-3
	Grade B	2.3 to 2.5	5–10	A-1
	Grade C	2.2 to 2.4	7–15	A-7 or A-6

Qualitative Descriptions of Classifications in Table I:

Reef coral.—Composed of accumulated skeletons of coral polyps and nullipore algae with sand, clay, shells, etc. Growths retain original form but are often cemented together. Found attached to top and upper sloping faces of growing reefs. Usually obtained by dragline or clamshell operations, sometimes accompanied by blasting, resulting in sandy agglomerates of various gradations. Satisfactory for military road and runway surface or base, for stabilized second-class road and runway surface, and, when properly graded, for intermediate- or low-grade concrete. A firm to hard in-place foundation material.

Lagoon coral.—Composition similar to reef coral, but contains very few cemented fragments. Found in reef lagoons mixed with coral sand and clay and often with sand and clay of volcanic origin. Obtained in useful form sometimes by clamshell but more often as a by-product of hydraulic dredging, which operation washes out most of the clay and pulverizes the softer coral, leaving usually well-graded mixtures of sand, gravel, and small boulders. Uses same as those of reef coral.

Coral sand.—Mostly disintegrated reef coral. A sand usually having a preponderance of flat particles. Found in lagoons, on beaches, and in reef cavities. Usually structurally and chemically satisfactory as a concrete sand, but often poorly graded.

TABLE II.—PROPERTIES OF CORAL REEF MATERIALS USED IN GUAM TESTS.

Sample	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
Classification	Grade B Cascajo	Grade B Cascajo	Grade B Cascajo	Grade B Cascajo	Grade A[a] Cascajo	Grade A Cascajo	Limestone[b]
Cumulative percentage passing:							
1½ in. sieve	100	100	100	100	100	100	100
¾ in. sieve	96	83	93	90	76	85	75
⅜ in. sieve	85	...	71	68	48	69	51
No. 4 sieve	68	50	49	46	38	52	43
No. 8 sieve	50	40	34	24	27	34	35
No. 16 sieve	36	30	22	15	17	24	23
No. 30 sieve	21	24	15	11	6	13	15
No. 50 sieve	9	18	5	9	2	3	7
No. 100 sieve	2	14	2	1	1	1	3
No. 200 sieve	...	10	...	...	...	...	1
Physical Properties:							
Bulk Specific gravity	2.20	2.1	2.56	2.31	2.45	2.34	2.65
Unit weight dry rodded, lb. per cu. ft.	98	98	101	92	85	104	96
Absorption, per cent of dry weight	12	10	11	4	5	8	1.5
Maximum dry density, lb. per cu. ft.[c]	...	116	110	114	118	116	...
California bearing ratio at 0.2 in. penetration[d]							
Pit run material	100	142	115	100	155	125	...
With 3 per cent cement by volume.	...	406	...	...	...	...	...
Organic Impurities by A.S.T.M. Method C 40 - 33	0	...	2	1	1	1	0

[a] Crushed.

[b] Crushed and graded. Contained 20 per cent coral sand by weight.

[c] Compacted at optimum moisture content (9-13 per cent by dry weight under 2000 psi. static pressure).

[d] After 4 days soaking. Procedure as in Standard Specifications, California Division of Highways, 1945. Swell during soaking was 1 per cent or less for all specimens.

Limestone.—Dense, relatively pure limestone containing some dolomite and minor clay streaks. Ancient coral reef altered by solution and subsequent crystallization and elevated by mountain-building forces. Often found in steep, high bluffs. Obtained by quarrying and crushing operations, which produce a good concrete aggregate with certain grading deficiencies. When used in place provides a cavitied rock foundation.

Limestone sand.—Dense, crystalline, rounded limestone grains, apparently the result of mechanical weathering of limestone. Found as an alluvial deposit.

Grade A cascajo.—Usually limestone fragments with some residual sandy loam resulting from partial decomposition and disintegration of reef limestone. Often found in bluffs. Obtained by quarrying and crushing, which produce a fair concrete aggregate inferior to limestone. A hard in-place foundation material.

Grade B cascajo.—Either (*a*) residual sandy loam and limestone fragments, resulting from more extended or severe weathering of limestone than for Grade A, or (*b*) old deposits of reef coral, lagoon sediments, or bedded reef talus. Usually found in hills or less-pronounced bluffs. Obtained by shovel operations or by quarrying. Pit-run material is frequently well-graded for use as road base, military road and runway surface, stabilized second-class road and runway surface, or intermediate-grade concrete. Contains excellent binder. A firm in-place foundation soil.

Grade C cascajo.—Composition similar to Grade B, but containing a large proportion of residual clay.[4] Applies in general to any tropical calcareous material too weak or too clayey for use as aggregate or base. Frequently found in lowlands. Obtained by earth-moving methods. A moderately firm in-place foundation soil.

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[4] Chemical composition of the clay fraction of cascajo varies depending upon geologic origin (**6**). In general, it consists mainly of widely varying proportions of compounds of iron, calcium, silicon, and aluminum. Cascajo where found on land is commonly overlain by a thin blanket of residual red clayey soil.

PROPERTIES OF UNTREATED MATERIALS

The very great usefulness of the various calcareous earths has been well established by the experience which is summarized in the above classification. It appears that all classes of coral, limestone, and cascajo, except for Grade C cascajo, can be used effectively for both (*a*) base, temporary surface, or stabilized second-class surface for roads and runways, and (*b*) aggregate for appropriate grades of asphaltic and portland cement concrete.

Many miles of cascajo-surfaced and coral-surfaced roads and runways are in use in tropical lands today (**15, 16, 21, 24, 26, 35, 37**). Where placed in suitable thicknesses, these surfaces withstand structurally the action of light to medium traffic in both dry and wet weather. However, two important defects are present: (*a*) the compacted surface erodes badly, developing large ruts and gullies during the intense tropical rainy seasons; (*b*) during the dry seasons the dust problem is acute. Where used as base course, the above defects are cancelled, and properly-selected cascajo or coral forms an eminently satisfactory base. The author was unable, either logically or experimentally, to discover any indication of chemical setting of either coral or cascajo; furthermore, neither gave indication of being chemically active when used as aggregate in either soil-cement or concrete.

Table II gives data on the physical characteristics of six typical samples of cascajo and one of limestone. The maximum dry densities and California bearing ratios of all materials tested are high, indicating very good stabilization properties. A fairly wide range of gradation is apparently permissible.[5] No samples of Grade C cascajo were tested, but experience has indicated this material to be undesirable for use as aggregate or as base for roads or runways.

Previous papers (**19, 25, 29, 30,** and **32**) give information on the physical properties of typical corals. Coral and cascajo have very similar engineering characteristics; the differences in their behavior are attributed to the higher clay content of the cascajo, which gives to Grades A and B somewhat better binding properties.

Sand-blasting experience with coral sand has been generally unsatisfactory. Some sand-blasting tests were made on Guam with typical coral beach sands and crushed limestone, using high-grade silica sand as control. Results indicated the natural sands and properly graded crushed limestone to be about equally effective, but both were only about half as effective as the silica sand. The coral sands disintegrated more rapidly than the limestone or silica sands. Tests were made on rusted steel sheet piling.

TABLE III.—REPRESENTATIVE FOUNDATION CHARACTERISTICS OF SOME CORAL REEF MATERIALS AT GUAM.

Classification	Angle of Internal Friction, deg.	Cohesion, psi.	Unconfined Compressive Strength, psi.
Limestone	..	....	6000
Grade A cascajo	28	1300	....
Grade B cascajo	18	1000	....
Grade C cascajo	10	200	....
Coral and cascajo hydraulic dredge fill	35	0	0

Extensive use has been made at Hawaii, the Phillipines, Guam, and elsewhere of the hydraulic dredge fill obtained from lagoon sediments and submerged cascajo (**28**). Many of the sediments are too clayey for structural use in place, but since the dredging process washes out the clay the fill is in practically all cases a friable sand-gravel mixture containing boulders up to perhaps six inches in size. This fill compacts naturally to a density of about 110 lb. per cu. ft. Where placed in suitable thickness on suitable base, it makes good foundation for pavements and footings.

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[5] The sieve analyses reported were made dry. It is possible that the low indicated percentages of fines are due to adhesion of the fines to the coarse particles.

Day (18) describes the construction of a major breakwater using limestone blasted from an emerged reef.

FOUNDATIONS AND EARTH STRUCTURES

Practically all coral reef materials except some of the geologically young lagoon sediments have merit as in-place foundation materials. All of the materials listed in Table I, with the exception of Grade C cascajo, exhibit high bearing capacity, skin friction, passive resistance, and low active pressure; also they are relatively incompressible. The values given in Table III are for typical Guam materials; values for other materials may vary widely from those given here. Samples tested were 2-in. cores from borings.

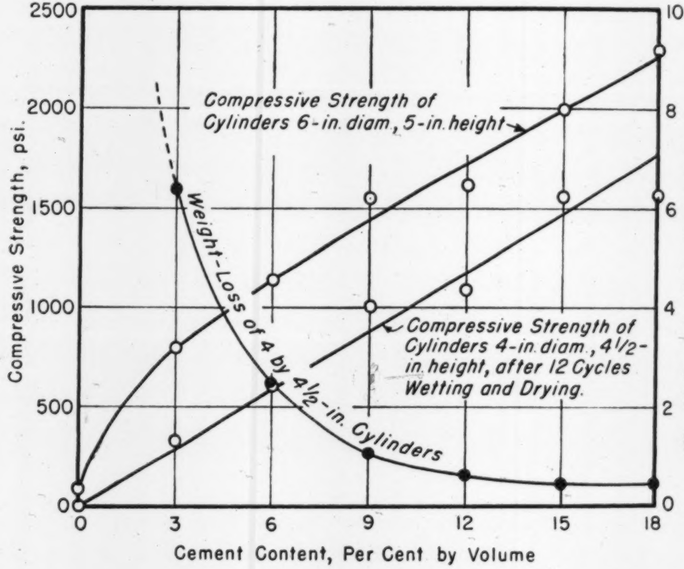

FIG. 2.—Strength and Durability of a Typical Cascajo-Cement Mixture.

Aggregate: Cascajo sample No. 2 (Table II). A.S.T.M. Type I cement, Golden Gate brand, ignition loss 1.8 per cent Curing at 80 F. 6 by 5 in. cylinders moist-cured 28 days prior to test; each point represents two specimens. 4 by 4½-in cylinders moist-cured 7 days, then submitted to 12 cycles of wetting, drying, and brushing, then tested; each point represents three specimens; 0 per cent-cement specimens disintegrated after first cycle.

Perhaps the greatest foundation difficulties with deposits of these materials arise on account of their nonuniformity and their irregular configuration. Piles may penetrate several feet of firm or hard soil and then plunge into a large clay-filled cavity; also piles may reach bearing at widely varying depths at locations only a few feet apart. This makes the exploration problem difficult.

Soft clayey lagoon sediments may extend to considerable depths in large lagoons, so that major structures built thereon require expensive foundations. The presence of coral fragments up to boulder size complicates the drilling and sampling problem and makes uncertain the results of laboratory shear tests.

SOIL-CEMENT MIXTURES

Experience with the excellent compacting qualities of Grade B cascajo, coupled with knowledge of the general adaptability of similar soils to the soil-cement method of construction, led to a laboratory investigation of a typical Guam cascajo-cement. It was believed that the addition of small proportions of cement would improve the good stability and the poor dusting and eroding qualities of the compacted raw cascajo. The sample tested was No. 2, Table II. Investigations covered the range of A.S.T.M. type I Portland cement contents from 0 to 18 per cent by volume in increments of 3 per cent. Test specimens were 6 by 5 in. and 4 by 4½ in. cylinders.

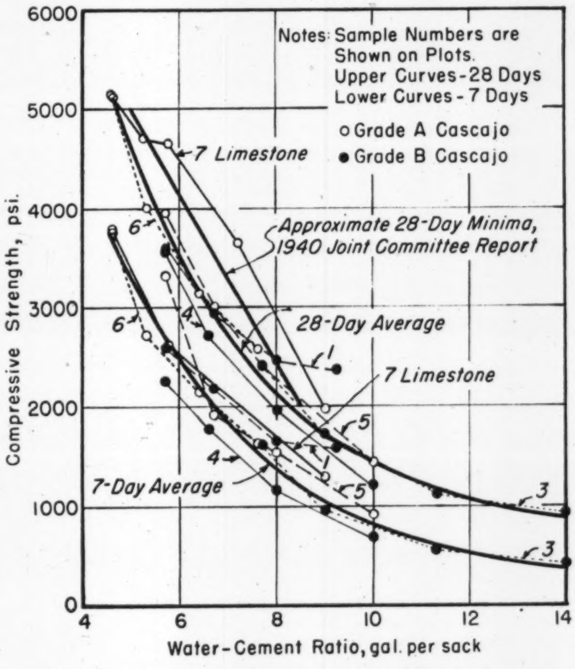

FIG. 3.—Compressive Strength of Cascajo Concrete.

Specimens, 6 by 12-in. cylinders. A.S.T.M. Type I cement. Moist curing at 80 F. Each point represents three specimens. Sample No. 4, 1-in. slump; all others 3-in. slump.

Figure 2 shows the strength and durability results. The 6 by 5-in. cylinders were molded in one layer at optimum moisture content under 2000 psi. static pressure and were tested in compression after 28 days moist curing. The 4 by 4½-in. cylinders were molded and tested as prescribed in A.S.T.M. Method D559 - 44T,[6] which requires 7 days moist curing followed by measurements of loss in weight after each of 12 consecutive cycles of wetting, oven drying, and wire brushing. Upon completion of the wetting-and-drying tests, the specimens were tested for compresive strength.

Loss in weight of the 3 per cent cement specimens in the wetting-and-drying test was 6½ per cent. For U.S. Public Roads Administration Group A-1 soils, the Portland Cement Association recommends a maximum limit of 14 per cent (31). Strength increases rather uniformly with cement content, achieving about 2000 psi. at 28 days with the 6 by 5-in. cylinders at 15 per cent cement by volume; this corresponds to about four sacks of cement per cubic yard of cascajo. By way of comparison, it may be observed that the compressive strength of ordinary 28-day 4-sack-per-cu. yd. concrete (6 by 5-in. cylinders) is only slightly in excess of 2000 psi. (23).

The value of California bearing ratio shown for sample No. 2, Table II, increases nearly three-fold with an addition of only 3 per cent cement.

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[6] Standard Method of Wetting-and-Drying Test of Compacted Soil-Cement Mixtures (D 559 – 44), 1946 Book of A.S.T.M. Standards, Part II, p. 679.

The typical cascajo tested is thus indicated to be highly adaptable to the soil-cement method of construction. These results are in general agreement with those obtained by Naval Construction Battalions using coral (**25**, **29**). There are deposits of cascajo or coral, capable of yielding substantially as good results, to be found at any reef-built or reef-flanked land. The techniques of selection of cascajo or coral and of design of soil-cement mixtures are the same as those developed for application to soils in the temperate zones (**31**).

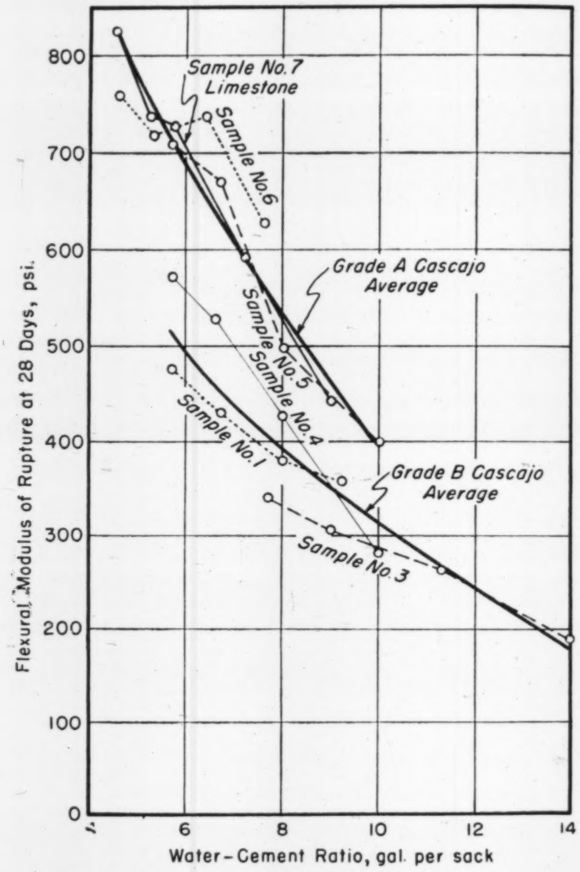

FIG. 4.—Flexural Strength of Cascajo Concrete.

Specimens, 6 by 6 by 22-in. beams. Age at test: 28 days. Moist curing at 80 F. Each point represents three specimens. Sample No. 4, 1-in. slump; all others 3-in. slump.

CONCRETE

Grieb (**20**), Nutter (**27**), Perry (**29**), Rasmusson (**32**), and others (**13, 14, 17, 22, 33, 34, 36**) have published information on concretes made with coral aggregate with some reference to materials that may have been cascajo. Naval Construction Battalions made extensive use of coral aggregates and of cascajo aggregates on the Pacific islands during the recent world war. Probably the most complete experimental study of coral concrete was made under the direction of A. E. Lindau (**25**) at the 14th Naval District Public Works Concrete Laboratory, Pearl Harbor, T.H., in 1944; his findings are summarized in papers by Perry (29) and Rasmusson (32). To the best of the author's knowledge, however, no record has been published on the concrete-making properties of cascajo, considered as a distinct material. Since on the larger geologically older islands cascajo can often be found which is either considerably more accessible than coral, or of superior structural quality, or both, it is pertinent to know the limitations of cascajo as an aggregate. The following test program was carried out with this in mind.

Five representative Guam cascajos, two of Grade A and three of Grade B, were selected for study. They are identified as sample Nos. 1, 3, 4, 5, and 6 in Table II, where their gradations and physical properties are shown. Included for comparison is a sample, No. 7, of crushed limestone aggregate, with the deficiency in fines made up by addition of 20 per cent coral beach sand by weight. All cascajos were pit-run, except for sample No. 5, which was crushed but not graded.

One hundred and fifty 6 by 12-in. cylinders and seventy-five 6 by 6 by 22-in. beams were made for testing in compression and flexure respectively. Cylinders were tested at ages of 7 and 28 days, beams at 28 days. Curing was in air at 100 per cent relative humidity at 80 F. Four classes of concrete, having cement contents of 4, 5, 6, and 7 sacks of A.S.T.M. type I cement per cu. yd., were mixed in the laboratory. The water content was adjusted in each case to give a slump of 3 in., except for sample No. 4 where a 1-in. slump was the maximum practicable due to extremely low water-carrying capacity of the material

Perhaps the most interesting of the results is shown in Fig. 3, where the variation in 7-day and 28-day compressive strength of each of the five cascajo concretes with water-cement ratio is compared. The significance of this figure is appreciated when it is observed that all five curves for each age fall very close to one another, so that single representative curves can be drawn for the 7-day and the 28-day compressive strengths with no differentiation as to cascajo grades.

Extension of the above result is shown in Fig. 4, where variations in 28-day flexural strength with water-cement ratio are plotted. Separate curves for the Grade A (samples Nos. 5 and 6) and the Grade B (samples Nos. 1, 3, and 4) cascajo were required by the data and seem logically justified because of the less sound condition of the Grade B cascajo. This condition would tend to have a much more marked effect in a flexure test where the failure occurs in tension than in a compression test where the failure is predominantly one of shear.

Relative performance of cascajo concrete may be judged on a water-cement ratio basis by comparison with the performance of limestone concrete (sample No. 7) and of minima obtained with average American concretes. This comparison is made in Figs. 3 and 4. The 28-day compressive strengths of the cascajo concretes are well below those of the limestone concrete but not greatly below the representative minima given in the 1940 Joint Committee Report (23). The 28-day flexural strengths of the Grade A cascajo concretes are approximately the same as for the limestone concrete (sample No. 7) while those of the Grade B cascajo concretes are materially less.

Comparison of the cascajo concretes on the basis of economy was made by using cement content as an argument. No clear relationship that could be applied approximately to all cascajos was found (or expected) between cement content and strength. Figure 5 shows the wide variation of results. Gradation and particle shape, and perhaps also organic impurities, apparently enter the picture strongly, for the quantity of water-cement paste of a given richness required to fill the voids and produce a given workability varies widely for different aggregates. All five cascajo concretes had good workability and little or no bleeding except for sample No. 4, which had harsh consistency, bled projusely, and could not practicably be molded at the 3-in. slump used for the others. No clear relationship has been found between gradation and cement content for a given strength.

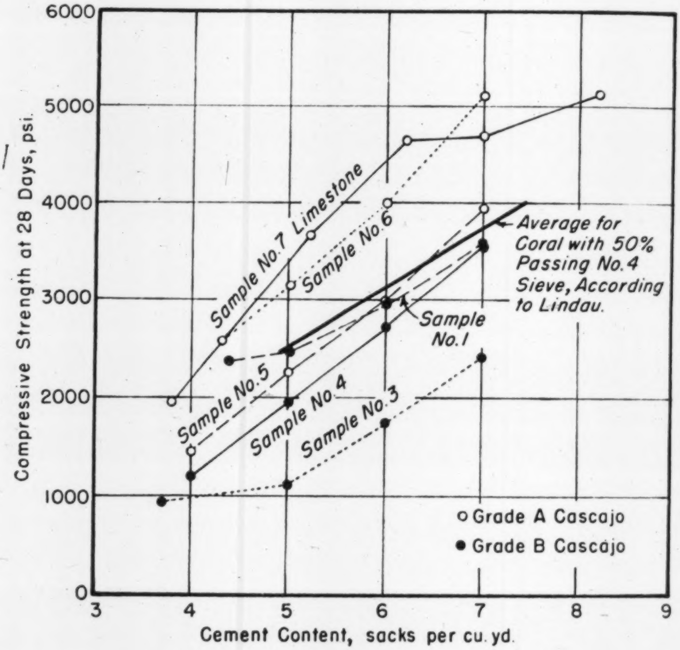

FIG. 5.—Economy of Cascajo Concrete.
Age at test: 28 days. See caption to Fig. 3.

The average of the cement content-strength curves for the five cascajo concretes tested lies close to the average reported for coral (with 50 per cent passing the No. 4 sieve) by Rasmusson (**32**). (See Fig. 5.)

For design of concrete mixes with pit-run aggregate, the water-cement ratio method of strength prediction is indicated by the above results, with trial batching to determine water-cement paste content for a given workability. This will usually result in a decision as to which of several available cascajos or corals to use, or as to whether coral or other sand must be added to fill out grading deficiencies. Graded-aggregate concrete probably will not be justified except when using Grade A cascajo, limestone, or unusually sound reef coral; experience with all three materials has shown that all of the accepted methods of mix design are applicable and will permit reasonable strength-prediction.

CONCLUSIONS

1. Confusion will be avoided in utilizing coral reef materials if their complex and variable origin is recognized. The

term "coral" should be restricted to its proper technical application and the terms "limestone" and "cascajo" used when appropriate.

2. Problems involving design and construction using the coral reef materials can be solved by the methods developed for use with the better known continental materials. There is no evidence of chemical "setting" of untreated coral or cascajo.

3. Coral or cascajo suitable for excellent road or runway base and treated surface can be found on any reef-built or reef-flanked land.

4. Practically all of the coral reef materials except for recent lagoon sediments and Grade C cascajo are excellent in-place foundation materials.

5. Coral and cascajo are generally highly adaptable to improved stabilization by the soil-cement method. Some cascajos, in particular, show great improvement in their already good structural characteristics with addition of very small percentages of cement.

6. Crushed and graded limestone makes good concrete aggregate. Crushed and graded Grade A cascajo makes a satisfactory concrete aggregate. These materials can usually be found in the geologically older emerged reefs. Both have grading deficiencies in the fine aggregate.

7. For design of intermediate-grade concrete with pit-run coral or cascajo aggregate, the water-cement-ratio method of strength-prediction is best adapted, with trial batching to fix the water-cement paste content.

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THE PROCEDURE AND SIGNIFICANCE OF CHEMICAL AND MINERALOGICAL TESTS ON SOILS*

By V. F. B. de Mello[1] and T. William Lambe[1]

Two different approaches can be used to determine the properties of soils involved in a problem of soil mechanics. The first approach consists of subjecting each soil in question to standard engineering tests, in the field or laboratory or both, to determine properties such as permeability, shear strength and compressibility. The second approach consists of two basic determinations: the nature of component parts of the soil and the detailed geological history of the soil since its deposition or residual formation. In this second approach, the engineering properties would be predicted from the knowledge of the properties of individual components and the history of their association and development.

The first of the above approaches is now in common use. It has the disadvantage of usually requiring many tests for every problem. While the development of knowledge to the stage where the second approach will be feasible now seems far in the future, the use of a modified form of the second approach to supplement the first is practical at the present time. In other words, the number of required engineering tests may be substantially reduced if physical properties of the soil in question can even be approximately predicted from the results of chemical and mineralogical tests. In fact, the use of identifying and classifying tests is a limited, but very practical, form of this modified approach. Also, the use of some parts of the second approach along with the first helps one to develop judgment and a "feel" for soil behavior.

It must be emphasized that the relation of mineral and chemical composition to the engineering behavior of a soil is known only slightly. Much research is needed to define more clearly this relationship. As this reservoir of knowledge is increased, the value of the tests presented in this paper will likewise increase. Although some of the tests are still in the development stage, it is felt that some form of these tests will eventually become standard for the more completely equipped soil mechanics laboratories. The different tests are presented herein as separate determinations, but it should be emphasized that to a certain extent they are interrelated. For example, for best interpretation of the results of a differential thermal analysis, the results of tests for certain chemicals, the ion exchange capacity, and the nature of the exchangeable ions should be known.

In the following pages, an attempt is made to present the significance and procedure of the more important chemical and mineralogical soil tests. The material for this paper was obtained from a study of pertinent literature and from research in the soil mechanics laboratory of the Massachusetts Institute of Technology. Many of the tests were developed by agricultural scientists and thus had to be modified for use in soil mechanics. Likewise, some of the chemical tests were developed by chemists interested in precise chemical analysis and they, in turn, had to be modified. Therefore, it is felt that the contribution of this paper lies in the development and modification of these tests for the engineer of soil mechanics.

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The tests which are described in the following pages are:

1. Identification of soil minerals
2. Determination of the hydrogen-ion concentration of soil
3. Detection of deleterious substances
4. Determination of exchange capacity and exchangeable bases

IDENTIFICATION OF SOIL MINERALS

The determination of minerals in the coarser grained soils is not presented herein for two reasons, namely, the actual determination normally does not present a major problem and, in general, the engineering properties of cohesionless soils are not greatly affected by the nature of the mineral.

It was originally thought that the complete study of the component parts of a soil entailed only the determination of the chemical elements present. It was soon discovered that knowledge of what elements were present was not enough, but the structural arrangement of these elements must be known. From the viewpoint of many geologists, clays are soils composed of the so-called clay minerals—they being basic units built of unique atomic arrangements. It must be pointed out that many natural soils may have a large proportion of grains in the clay size range which still are not clay minerals.

In soil mechanics there seem to be three important clay mineral groups: kaolinite, illite, and montmorillonite. These groups consist of essentially the same chemical elements, but the structural arrangement of these elements is different. While there remains much to be learned about the engineering properties of the clay mineral groups, some qualitative data are available on these properties. Kaolinite is the least active of the clay minerals: it has the highest permeability, the lowest water adsorption, and the lowest compressibility of the three clay minerals. Montmorillonite is at the other extreme, having the lowest permeability, the highest water adsorption, and the highest compressibility. The illite group is between these extremes; some of the illites approach the kaolinites, while others approach the montmorillonites. Only a little is known quantitatively on the properties of mixtures of the clay minerals. Practically nothing is known of the engineering properties of bodies which are not clay minerals but are in the colloidal size range.

There are three methods available for the identification of the clay minerals or other minerals of "clay size" particles: the differential thermal analysis, X-ray diffraction, and the electron microscope. The differential thermal analysis seems to be the most practical of the three methods for use in a soil mechanics laboratory for qualitative and semi-quantitative mineral determination, although the results may often be very difficult to interpret. Therefore, only the differential thermal analysis will be discussed here.

DIFFERENTIAL THERMAL ANALYSIS

The differential thermal analysis consists of heating at a uniform rate the soil in question and an inert substance from around 100 C. to over 1000 C. During the heating, changes in structure of the soil occur which result in the release or imbibition of heat. Since the inert substance does not undergo any structural change, the difference in temperature between the soil and the inert standard, as measured by a differential thermocouple, is a measure of the thermal change in the soil. Each pure mineral has a unique curve of thermal change *versus* temperature.[2] The apparatus is not described here because detailed descriptions are available in the literature (**21**).[3]

Test Procedure:

Analyzer Calibration.—Before the minerals in a given fine-grained soil can be identified, the analyzer must be calibrated by separately obtaining standard thermal curves for each unique component whose recognition is desired. Each component is tested by the procedure described below for subsequent testing of a soil of unknown components.

Sample Preparation.—The specimen to be tested should first be dried at a temperature of 50 C.[4] Drying at high temperature can throw the early portion of the thermal curve off by driving off more water than is desired or possibly causing the grains of the soil to break down. If the specimen tested is a clay, no fractionation is necessary; but if the specimen has coarser grains present, all material coarser than the No. 200 sieve should be removed.

The dried specimen is next put in the sample holder. During the filling, care should be taken to keep the thermocouple centered. The amount of specimen used for the test and the void ratio obtained should be similar to that of the inert material used as a standard. This desired condition can be approximately obtained by using the same arbitrary standard procedure for all packing.

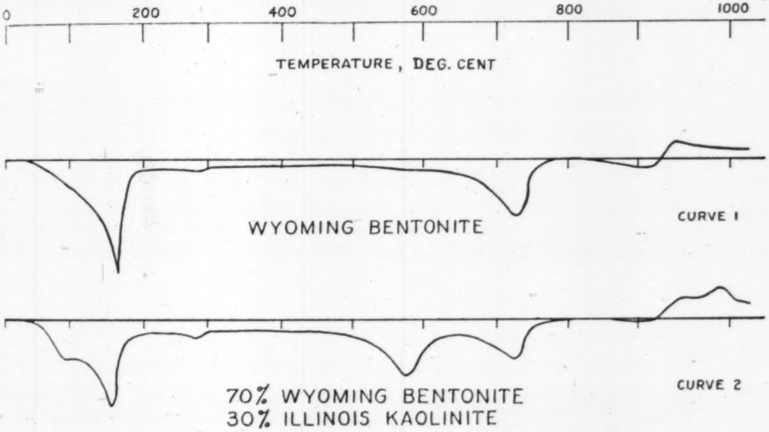

FIG. 1.—Differential Thermal Analyses.

Sample Heating.—The furnace is next placed around the holder and heating at a uniform rate is started. A continuous record of the thermal reactions is made by a recorder.

Interpretation of Results.—There are two things to be determined from the thermal curve: the different minerals or impurities present and the approximate amount of each. The minerals are identified by the characteristic temperatures at which the thermal changes occur. For example, kaolinite has two tell-tale changes, an endothermic reaction in the neighborhood of 575 C. and an exothermic reaction in the neighborhood of 950 C. The proportion of any given mineral in the tested soil is approximately equal to the ratio of the area under the curve of the tested soil divided by the area under the standard curve of the pure mineral. This interpretation of the results can best be shown by an actual example (Fig. 1).

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[2] Substances other than minerals possess unique thermal curves; therefore, the differential thermal analyzer may be used to identify more than the mineral. Work is being done on the thermal analysis of organic substances by the Massachusetts Institute of Technology, Geology Department and on the thermal analysis of building materials by the M. I. T. Engineering Construction Department.

[3] The boldface numbers in parentheses refer to the bibliography appended to this paper, see p. 987.

[4] Current research indicates that it may be necessary to prepare some specimens much more carefully. If organic matter is present in the soil, it may be desirable to remove it before testing.

Example.—Curve 1[5] is the thermal curve for a Wyoming bentonite; curve 2 is the thermal curve for an artificially prepared mixture of 70 per cent bentonite and 30 per cent kaolinite. If curve 2 were that of an unknown soil, the presence of bentonite and kaolinite would immediately be recognized from the characteristic temperature at which thermal changes occurred.

A semi-quantitative analysis[6] of curve 2 depends on the approximate relationship, from the theory of thermal reactions, that the amount of reactive mineral is proportional to the area enclosed by a bump on the curve. Thus the proportion of bentonite in the sample of curve 2 is equal to the ratio of the area under the curve in the 700 C. range in curve 2 to that in curve 1. The value of the ratio (multiplied by 100), 70 per cent, agrees with the predetermined proportion of bentonite.

DETERMINATION OF THE HYDROGEN-ION CONCENTRATION OF SOIL

Hydrogen-ion concentration (pH) of a soil is not a fundamental property characterizing and defining its engineering behavior. It is true, however, that there are significant correlations between the pH of various soils and the weathering processes and weathered products which define the soil, even in terms of engineering properties. Agricultural chemists have used to great advantage the correlations between pH and the properties of soils as classified by them.

Although pH determinations must take a modest position beside such determinations as that of the mineral constituents of soil, which purports to determine the soil properties by defining its components, it must be conceded that among chemical tests for a soil, determination of the soil reaction (pH) stands as important in its own right. Highly acid soils are injurious to steel and cement alike, and it has often been reported that highly alkaline soils are very detrimental to the adequate setting of cement. Furthermore, the interpretation of the results of other soil chemical tests, such as the tests for exchangeable bases associated with the soil, is facilitated by knowledge of the soil pH. M.D. Catton concluded from a study of about three hundred soil samples, that "if organic content is 5000 ppm. or over, the soil will also be acid. It does not show that if the soil is acid it will have a high organic content" (10).

For the development of a suitable method of determining pH in soils, we are indebted to the agricultural chemists who have long been interested in this problem. Both electrometric and colorimetric procedures for measuring pH have been in common use, the former being used for soil suspensions, the latter more commonly with soil extracts. While new colorimetric procedures are steadily being developed and suggested for use, especially in cases where precision may to some extent be sacrificed for economy of time and money, the electrometric procedures have already developed to the point of general acceptance. The present discussion will, therefore, focus on electrometric methods of determining pH, although it is emphasized that for many cases some specific colorimetric procedure may prove quite adequate and may be selected for various practical reasons.

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[5] Curves 1 and 2 were obtained by Kulp and Lambe with the analyzer of Kerr and Kulp (21).

[6] The above example was selected to illustrate the principle of qualitative and semi-quantitative analysis. It is not to be inferred that the analysis of any given unknown soil will be as easy and definite as the example.

Electrometric measurement of pH in soils is analogous to measurement of pH in solutions. An electrode, the potential of which is a direct function of hydrogen-ion concentration, is immersed in a solution or suspension, connected with another standard half-cell (usually the calomel) and the electromotive force of the cell is measured potentiometrically. The definition of pH properly applies to aqueous solutions; in the case of two- or three-phase systems such as soils some question may be raised as to the meaning of the term "pH." However, the term as used in soils refers to the reading obtained using some electrode scheme on a commercial instrument, such as a "Beckman pH meter"; the reading if made with due precautions is indicative of the acidity or alkalinity of the soil.

Apparatus:

The apparatus consists of two essential components: the electrode and electrode vessel, into which the sample is placed, and the measuring equipment including a standard half-cell, a potentiometer and a galvanometer. The commercial units are compactly arranged providing the standard assembly of potentiometer, galvanometer, and standard half-cell, and providing some specific electrode scheme; as a result, usually, upon placing the sample in the electrode vessel, by merely turning on a switch or two, the pH may be read directly on a dial. Retention of this facility is greatly favored: hence the measuring assembly utilized in commercial units will be assumed herewith. The questions lie in the selection of electrode scheme and in the treatment of the soil samples prior to and during testing for pH.

Soil Sample:

It is widely recognized that a variety of factors affect readings of pH in soils: variations of the amount of carbon dioxide in the system, the use of distilled or tap water, drying the soil sample, variations of the soil-water ratio, grinding of the soil sample, and even extended storing of soil samples at constant water content—all these factors contribute in some way to modification of the pH of the soil. These various effects will not be discussed individually but are merely mentioned in order to emphasize the point that since we are interested in determining the pH of the soil *in situ*, there are some definite precautions that must be observed in making pH measurements on soil samples.

Fresh samples should be used, if possible; the soil should not be dried or ground; if possible, the pH reading should be taken with the soil at its natural water content; if it is necessary to increase the water content of the sample, boiled distilled water should be used. If the *in situ* pH of the soil is not determined, the determination of the pH of a sample is of little value unless the conditions of test are specified.

A variety of samples at low natural water contents may make it necessary to increase the water content considerably before a suspension is obtained on which pH measurements can be made. Standardization of samples to a soil-water ratio of 1:5 has been suggested, recognizing that the pH thus determined is different, but not widely so, from the pH of the soil at natural water content. "When a more accurate idea of the pH at low moisture contents is desired, this can be obtained by extrapolation of the graph connecting the hydrogen-ion concentration determined at three soil-water ratios (preferably 1:5, 1:25, 1:125). Plotting the pH values against the log of the soil-water ratios lends itself best to this treatment," (39).

More recently the use of the glass electrode has been adapted to pH readings in soils at lower water contents. Consequently, in the field of agriculture the recent trend is toward standardization with the use of soil samples at the moisture equivalent, as a convenient lower limit at which pH readings are still reliable.

Electrode Scheme:

Four major electrode schemes have been developed and used to some extent over the years, but gradually the use of the glass electrode in connection with a commercial pH meter, has superseded the others in view of its reliability coupled with several advantages of practicability.

A discussion of the hydrogen, quinhydrone, and antimony electrodes will not be within the scope of this brief paper. With some modifications they have been very successfully used in many instances. The advantage of the glass electrode, however, is that no great refinements are necessary. It is well adapted to use with soil samples even at rather low moisture contents. At low water contents, precautions have to be observed of compacting the soil sample so as to make close contact with the glass electrode.[7] At higher water contents, in soil suspensions, some agitation scheme is necessary in order to keep the soil in homogeneous suspension.

DETECTION OF DELETERIOUS SUBSTANCES

In a soil there may exist some substances which have deleterious effects on the soil itself or on structural materials placed adjacent to the soil. One substance which has a pronounced effect on the engineering properties of soils is organic matter. Some organic matter by its very nature tends to lower the strength and increase the compressibility of the soil. For example, peat which is derived to a large extent from trees, leaves, small plants, etc., is very compressible and weak in shear strength. Also organic colloids can be absorbed by the soil in base-exchange reactions and other reactions (17). These adsorbed organic colloids greatly reduce the ability of the clay to imbibe water, thus reducing the swelling tendency of the clay and simultaneously reducing the shear strength of the soil at a given water content. Only a little is known of the magnitude of the effect of adsorbed organic colloids on the engineering properties of clays.

Substances in soils which may have serious effects on adjacent structural materials are sulfides, sulfates, carbonates, and organic matter. These substances may cause their damage either by being in actual contact with the structural materials, from their position in the soil, or by supplying reactable materials to the flowing ground water to form acids, bases, or salts.

The common structural materials used for pavements, piles, foundations, and walls are steel, wood, concrete and stone. The deleterious effects of the above named substances on wood and most sound masonry are so small that they need not be considered any further. Since steel is injured by acids, all of the substances must be considered as they are all potential acid producers. Piles driven into soils containing significant amounts of these potential acid producers may require special treatment such as an acid-resistant coating or some type of cathode protection. Steel is not attacked by hydroxides.

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[7] As mentioned earlier, water contents below a convenient lower limit should be avoided, since various sources of error arise, including difficulties due to the abnormally high electrical resistance involved.

Concrete can receive injurious effects from all of the above listed substances. The presence of organic matter can prevent cement from setting. The nature of attack of the sulfides, sulfates, and carbonates can be either chemical corrosion or crystal formation. Acids, bases and aggressive salts can actually chemically attack concrete; the degree of this attack depends on the concentration of the active substance as well as the type of aggregate used in the concrete mix. For example, certain aggregate constituents such as opal are seriously attacked by hydroxides. Crystal formation due to the evaporation of alkali-laden water from the surface of concrete may cause disintegration somewhat analogous to that caused by the freezing of water.

From the above brief discussion, one can see that it is desirable to have short, simple, chemical tests to detect the presence of sulfides, sulfates, carbonates, and organic matter in soils. The following simple tests have been selected for the detection of the presence of minute quantities of the above components. These tests, called "spot tests," are only qualitative as they are described. Based on the results of "spot tests" a complete quantitative analysis of the soil may be desired. Such a quantitative analysis may be time-consuming and may be of only small additional value until more is learned of the limiting concentrations that may be permitted with regard to the safety of the particular foundation. It must be remembered that the dangerous concentration of these substances may depend largely on ground water conditions.

Procedure:

Sulfides (15).—Add to the soil in question a few drops of azide-iodine solution. The formation of tiny bubbles of nitrogen indicates the presence of a sulfide in the soil. The stable azide-iodine solution is prepared by dissolving 3 g. of sodium-azide in 100 ml. of 0.1 *N* iodine solution.

In making this test it is helpful if a microtest tube is used; it should be held so as to get a background of strong light to aid in seeing the minute nitrogen bubbles.

Soluble Sulfates (31).—Add to the soil in question about 4 ml. of 5 *N* hydrochloric acid and stir; next add a little barium chloride solution. The formation of barium sulfate, which is a white precipitate, indicates the presence of a soluble sulfate. The hydrochloric acid is added to prevent the formation of barium carbonate or barium sulfite both of which are white precipitates.

It should be noted that the above test is only for soluble sulfates, but since these are the ones whose presence in soil is of interest, the test is sufficient for sulfate determination.

Carbonates.—Add a few drops of 5 *N* hydrochloric acid to the soil in a test tube which is equipped with a U-shaped delivery tube inserted in barium hydroxide. After heating the tube containing the soil, the formation of a white precipitate in the barium hydroxide indicates the presence of a carbonate in the soil.

In this test it is desirable to use microtest tubes and a capillary tube for the delivery tube to increase the sensitivity of the test. Often the application of heat is not needed.

The barium hydroxide must be stored carefully to prevent its reacting with the carbon dioxide in the atmosphere to form barium carbonate. This reaction can be prevented by venting the barium hydroxide solution through a drying tube containing crystals of sodium hydroxide.

Organic Matter.—Add a few drops of concentrated sulfuric acid to the soil contained in a test tube with a stopper and a U-shaped delivery tube inserted in barium hydroxide. Heat the soil and acid; the formation of a white precipitate in the barium hydroxide indicates the presence of organic matter. The above test is based on the sulfuric acid and heat oxidizing any organic matter present to free carbon dioxide which reacts with the hydroxide to form the insoluble barium carbonate. The same microtest tube set-up used for the carbonate test is used here. Since the above described test would also be positive for any carbonates present, it is essential to test the soil for carbonates before testing for organic matter. If there are carbonates in the soil they must be removed by the addition of hydrochloric acid (see previous test) before the organic test is made.

DETERMINATION OF EXCHANGE CAPACITY AND EXCHANGEABLE BASES

The importance of the exchange capacity of clays in determining engineering properties of clay soils has been justly recognized. The correlation between the engineering properties of clays and the type of clay mineral of which the clays are composed has already been pointed out. Further, it is known that the exchange capacities of the clay minerals similarly fall into the typical pattern noted for the other properties of the clays; montmorillonites have high exchange capacities, while the illites, and kaolinites have moderate and low exchange capacities. It might thus be stated, *a posteriori*, that there are definite trends of correlation between the exchange capacity and the engineering properties of clays.

However, the moment a few generalizations have been made with respect to such a correlation, it must be recognized that the nature of exchangeable base present cannot be disregarded. Recognition of exchange capacity entails recognition of the possibility of exchanging the adsorbed bases (cations); hence one speaks of a sodium-montmorillonite, calcium - montmorillonite, magnesium - kaolinite, and so forth, in each case specifying the exchangeable cation adsorbed by the clay. Most natural clays are not homoionic, that is they contain more than one type of exchangeable cation. But the distinction in properties between several homoionic varieties of a clay permits the estimation of the properties of heteroionic clay bodies. For instance, it is known that a sodium-clay tends to have a higher liquid limit, plasticity index, and swelling capacity, than a corresponding calcium-clay; this is similarly true of montmorillonites, illites and kaolinites, but quite naturally the differences in properties are most marked in the case of clays with high exchange capacities. If the properties of a sodium-clay and the corresponding calcium-clay are well established, the properties of a heteroionic clay composed partly of sodium-clay and partly of calcium-clay can be estimated to be intermediate.

It is not the purpose of this paper to elaborate on the ideas presented in the above paragraph, for soil mechanics literature has already disseminated those concepts. The above paragraphs are merely intended to emphasize the importance and significance of determinations of exchange capacity and exchangeable bases associated with a soil.

Test Procedure:

The limitations of space that must be imposed on this presentation make it necessary to present a summary outline procedure for determining exchangeable bases and total exchange capacity. It will not be possible to discuss the selection of the procedure recommended or the details of all the steps involved. The procedure is outlined for what appears to be the most complicated general case, namely, a saturated clay with the cations K^+, Na^+, Ca^{++}, Ba^{++}, Mg^{++}, Fe^{++}, Fe^{+++}, and Al^{+++} present both as exchangeable ions adsorbed on the clay particles and as free ions in the solution composing the pore liquid. The proposed logical sequence of testing is outlined in the following steps:

1. Determine the water content of the clay: this determination is necessary for the subsequent computation of the dry weight of clay used and the volume of liquid in which it is dispersed.

2. Simultaneously place a given weight of the wet clay (computed to give about 10 to 25 g. of dry clay) into a 250-ml. heavy-duty centrifuge bottle. Add a known volume (about 200 ml.) of dioxane, stopper the bottle and shake well to disperse the clay; addition of clean glass beads helps the dispersion on shaking. Then centrifuge at 2000 rpm. or higher.

3. Extract the clear supernatant liquid for analysis of cations present as soluble salts in the pore liquid. Aliquots of the solution are used, and computations are based on the assumption that the concentration of a particular ion is the same throughout the total volume of liquid. Analyze for Na^+ and Ca^{++} quantitatively· then detect the presence of other ions by qualitative spot tests; finally, if desired and justified by the indications of the qualitative tests, analyze quantitatively for some of these ions.

4. To the clay sediment in the centrifuge bottle add a known volume (as much as possible) of neutral *N* ammonium acetate solution. Shake and disperse the clay thoroughly, and recentrifuge. The clear supernatant liquid now contains all of the cations present in the pore liquid, in quantities that may easily be computed from the results of step 3; further it contains all of the replaceable ions originally associated with the clay, except for Al^{+++} which may not be replaced adequately by NH_4^+, and Fe^{+++} which, although replaced, has formed an insoluble precipitate with the acetate.

5. Use the supernatant solution from step 4 for quantitative analyses of Na^+ and Ca^{++}, and qualitative and quantitative analyses of the other ions as described in step 3.

6. To aid the replacement of Al^{+++} ions by NH_4^+ ions, add ammonium phosphate to the clay batch and shake well. The clay should now be essentially saturated with NH_4^+ ions; further, insoluble ferric acetate and aluminum orthophosphate will be precipitated.

7. Wash the clay, and iron and aluminum precipitates, with distilled water; this is best done by leaching, passing water through under suitable pressure.

8. Transfer the washed clay, and precipitates, back to a centrifuge bottle, noting the volume of water associated with the clay. Add a known volume of 5 *N* H_2SO_4 and stannic sulfate solution. Shake well, then centrifuge.

9. The clear supernatant solution is used for the determination of the total exchange capacity, and for the quantitative estimation of the exchangeable Fe^{+++} and Al^{+++} ions associated with the clay. One aliquot is used for the quantitative determination of NH_4^+ by the standard Kjeldahl procedure: the exchange capacity is very readily computed from this determination. Another aliquot is used for the estimation of exchangeable Fe^{+++} and Al^{+++}. For this determination it may be sufficiently satisfactory to separate the two ions by filtration after addition of an excess of

NH_4OH reagent, subsequently estimating the ions by ignition to the oxides.

10. The use of a check should not be neglected. The sum of the milliequivalents of the exchangeable bases must be equal to the exchange capacity, within experimental error.

The above procedure can naturally be simplified in certain cases, although as now proposed it is not unduly refined for engineering purposes. For the analyses involved in steps 3 and 5, the following suggestions may be helpful, although it is strongly recommended that more detailed study be given to the matter.

Qualitative Spot Tests:

Fe^{+++} 1. Put a drop of the test solution (acidify if necessary) on a white spot plate. Add a drop of potassium ferrocyanide solution. Formation of a prussian blue indicates Fe^{+++}.

Fe^{++} 2. Put a drop of test solution (acid) on a white spot plate. If solution is red, decolor by adding a few crystals of potassium fluoride in a paraffin-lined depression. Add a drop of α-α'-dipyridyl solution (2 per cent in alcohol). A deep red soluble complex cation indicates Fe^{++}.

$\left.\begin{matrix}Ba^{++}\\Ca^{++}\\Sr^{++}\end{matrix}\right\}$ 3. Put several drops of neutral or slightly acidic test solution on a black spot plate. Add indicator solution (lead sulfate dissolved in acetic acid solution of ammonium acetate). Cloudiness, or white precipitate indicates presence of this group.

Ba^{++} 4. Put a small quantity of solid tetrahydroxyquinone and potassium chloride on a white spot plate. Add a drop of test solution and a drop of water. A brown color (appearing first near undissolved reagent) which turns to red upon addition of 0.1 N HCl indicates Ba^{++}.

Al^{+++} 5. Remove any iron present by precipitation with NaOH. Then add a drop of test solution to alizarin paper (quantitative filter paper soaked in a saturated alcohol solution of alizarin, dried, stored in stoppered bottle). Hold over dish of NH_4OH until spot turns violet. Dry in oven. A change to red color indicates Al^{+++}.

K^+ 6. Dissolve a small quantity of sodium cobaltinitrite in a drop of water on a black spot plate. Add neutral or slightly acid test solution. A yellow crystalline precipitate indicates potassium.

The sensitivity of the test can be increased by adding a drop of silver nitrate solution, but before this is done, a drop of the test solution should be added to a drop of silver nitrate alone to find whether halides or NH_4 salts or other interfering salts are present in the test solution. These produce a thick white precipitate which would obscure the cobaltinitrite test.

Mg^{++} 7. Place a drop of neutral or slightly acid test solution on a white spot plate. Add a microdrop of N potassium hydroxide followed by a microdrop of iodine solution. (N iodine in 20 per cent KI solution.) Stir until the solution becomes brown from free iodine. After 1 min. add potassium hydroxide until solution becomes lemon yellow. If Mg^{++} is present, brown flecks are clearly visible in the yellow solution.

NH_4^+, Al^{+++} and such ions as form colored hydroxides under test conditions interfere.

Quantitative Tests:

1. *Sodium.*—Use a suitable aliquot part of the solution and evaporate it carefully to a small volume, then add more than ten times the volume of zinc uranyl-acetate reagent and allow to stand 30 min.: finally, gravimetrically filter the precipitate by suction, washing with small portions of the reagent, absolute alcohol, and ether. The weight of sodium is equal to 0.01495 times the weight of the precipitate (3).

2. *Calcium, Magnesium, possibly Barium, also Potassium.*—Use a suitably large aliquot part of the solution, concentrate it by evaporation and add a large excess of a saturated solution of ammonium oxalate. The precipitate of calcium oxalate is separated and washed with water by suction filtration, dried and weighed.

The filtrate from above is used for the quantitative estimation of magnesium, if desired. Evaporate it to dryness expelling ammonium salts, then dissolve it in dilute HCl and then precipitate magnesium ammonium phosphate as follows. Acidify the solution with 5 ml. concentrated HCl, add methyl red indicator, and add a 5- to 10-fold excess of the precipitant, a saturated solution of diammonium phosphate. Then add ammonia water (sp. gr., 0.90) slowly, while stirring, to neutralization. Stir for 5 min. or until the precipitate is well formed, then add a little excess ammonia water, stir for 10 min. Filter the precipitate after it has stood overnight, and then wash with water containing 3 per cent by volume of ammonia water. Ignite the wet filter paper and precipitate in a weighed platinum crucible at approximately 1000 C. to constant weight. The magnesium pyrophosphate is weighed.

Barium can further be obtained from the magnesium filtrate by precipitation as the sulfate.

After elimination of such ions as calcium, magnesium, and barium, as indicated above, the filtrate can be analyzed for potassium.

Evaporate to dryness, expelling ammonium salts. Dissolve in water and add twice the perchloric acid required to convert the salts into perchlorates. Evaporate to dryness with special attention to driving off all the excess perchloric acid; cool the beaker, rinse the inside with a little water and repeat the evaporation and heating. Dissolve the residue by adding 95 ml. of 95 per cent ethyl alochol and heating if desired. Chloroplatinic acid, 0.2 g. dissolved in 5 ml. of 95 per cent ethyl alcohol, is added to this solution, preferably hot, and after a few minutes digestion and vigorous stirring, the mixture is cooled to 0 C. and allowed to stand with frequent stirring at this temperature for over an hour. The precipitated solution is filtered through a sintered-glass crucible, the potassium chloroplatinate is washed with several portions of cold absolute alcohol, to free from sodium perchlorate. It is then dried and weighed.

The above discussions of the differential thermal analysis for mineral structure, the determination of soil pH, the identification of admixed chemicals, and the determination of base-exchange capacity with the concomitant analysis of the exchangeable ions associated with the soil complex have of necessity been summarized in view of the authors' intent to emphasize the perspective of the method of testing delineated. In conclusion it may be said that it is hoped that the field of soil mechanics will rapidly advance towards filling in the details, thereby simultaneously broadening the perspective, to the advancement of our understanding of soil behavior.

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DISCUSSION

Mr. Edward A. Willis.[1]—Of interest in connection with this paper is an article entitled "Michrochemical Examination of Soil Solutions," by James A. Kelley, published in the July, 1935, issue of *Public Roads*.

The report describes the study of concrete roads in New York and other locations and the crystal growth that was associated with them.

Mr. L. E. Gregg.[2]—We have carried out a certain amount of work in our Research Laboratories at the University of Kentucky. A report on that work was presented by Mr. J. H. Havens at the last meeting of the Highway Research Board in Washington. Incidentally, that project is being extended.

I want to congratulate the authors of this paper for bringing forth this very important and timely presentation on a phase of soils that, I think, has been neglected for a long period of time. They gave, in their data on the differential thermal analysis, something that enhances greatly mineralogical identification and analysis provided it can be controlled as much as they indicate.

In our work with the X-ray diffraction method, we have had great difficulty in determining the percentages of different clay minerals in a combination. For example, we would like to know whether we have, say, approximately 30 per cent illite, 20 per cent kaolinite, and 50 per cent montmorillonite in a soil with which we are working. And we cannot, with the X-ray method, differentiate them—or haven't been able to thus far—as closely as we think it should be done. If this can be accomplished invariably with the differential thermal analysis, then I recommend it very highly.

One point with which I would take exception is the suggestion that chemical and mineralogical properties can, in themselves, be more important than the strength of a material. I believe we should not overemphasize them as factors in soil mechanics. While they are fundamental in determining soil behavior, they are adjuncts or supplemental characteristics which can tell us much about the inconsistencies that we observe in our physical tests. Despite their importance and our efforts to reveal that importance, I would be the last to maintain that tests for these properties can replace entirely physical tests or other determinations for things that we really need to know.

Mr. E. J. Kilcawley.[3]—We have had the same experience as that pointed out by Mr. Gregg. We find that the thermal curves given by the differential method will vary with respect to the degree of fineness of the materials used. The degree of compaction of the sample will also have an effect.

We, like the authors, have also found it possible to determine the percentages of materials present from the differential thermal curve provided there are no more than two minerals present. We have, therefore, supplemented this method with X-ray diffraction and spectrographic analysis, using both internal and external standards. This does not, however, mean that the differential thermal analysis does not occupy an important place. But I believe that the differential thermal, X-ray and spectrographic analysis will all be needed to define materials as closely as is necessary in order that certain inconsistencies in physical tests might be better explained.

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[1] Senior Highway Engineer, Bureau of Public Roads, Washington, D. C.

[2] Associate Director of Research, Kentucky Department of Highways, Highway Materials Research Lab., Lexington, Ky.

[3] Professor of Soil, Mechanics and Sanitary Engineering, Rensselaer Polytechnic Institute, Troy, N. Y

I likewise agree with Mr. Gregg that these tests will not replace either the physical or the mechanical tests now used but they are needed in order better to explain the inconsistencies in results obtained in many cases.

MR. MILES D. CATTON.[4]—Some of the work that has been done on soil-cement, particularly our early work, brought out very clearly the importance and significance of the surface chemistry of soils. Perhaps a brief review of some of that early work will be of interest and value.

As test procedures were set up to investigate soil-cement mixtures, a pH determination was purposely included, and was conducted on all soils for several years to give histories and backgrounds as to the possible influence of pH on cement reaction in soils. This several years' work showed rather conclusively that the pH of the soil before cement addition had no discernible influence on the reaction of cement with the soil.

However the early work on soil-cement mixtures gave very vivid proof, at once, that the surface chemistry of soils was a predominant factor. This was shown by the fact that soils of apparent similar physical characteristics did not respond to cement treatment in the same way.

Recognition of this surface chemistry was evidenced by the Portland Cement Assn. setting up a fellowship at the University of Missouri, under Mr. Winterkorn, in the late thirties, and during a two-year period a series of tests was conducted on soils in which the adsorbed ion was controlled.

This work has been reported by Mr. Winterkorn to the Highway Research Board and will be found in its *Proceedings*.[5]

The summary of that work indicated that the adsorbed ion was an influencing factor, but the work possible to do in the two years did not permit evaluation of that influence. With some soils the changing of the adsorbed ion from one to another may have improved the cement reaction, but with other soils, those same adsorbed ions had a decreasing influence on the cement reaction. But that work in the thirties did point out that the surface chemistry of soils is a most important factor in the action of the soil from a practical standpoint. While nothing was uncovered which could be used, it was found that should this adsorbed ion be of an unfavorable character it was overcome by adding additional cement.

As part and parcel of the phenomenon of the surface chemistry of soils, we encounter soils which have a high organic content. Personally, I use the word "organic" advisedly, because the adsorbed chemical cannot be identified and I believe that surface chemistry is definitely involved. It was found that sandy surface soils in coniferous areas with high organic contents required high cement contents to properly harden. In these cases, cement contents by volume of the order of 20 to 30 per cent were required for normal hardening rather than the usual 10 per cent. After extended research, it was found that they became normal reacting soils after the addition of relatively small quantities of calcium chloride of the order of 0.6 per cent by weight or by adding about 20 per cent by weight of clayey soils.[6]

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[4] Manager, Soil-Cement Bureau, Portland Cement Assn., Chicago, Ill.

[5] Hans F. Winterkorn, Harold J. Gibbs and Rollie G. Fehrman, "Surface Chemical Factors of Importance in the Hardening of Soils by Means of Portland Cement," *Proceedings*, Highway Research Board, Vol. 22, p. 385 (1942).

[6] Miles D. Catton and E. J. Felt, "Effect of Soil and Calcium Chloride Admixtures On Soil-Cement Mixtures," *Proceedings*, Highway Research Board, Vol. 23, p. 495 (1943).

Here are practical, physical illustrations of the influence of the surface chemistry of soils on their behavior. So, while it may be said in general that the surface chemistry of soils has not received the attention from the general soils scientists that it might have, the literature will show that different individuals at different times during the past 15 yr. have recognized and given considerable weight to this very important phenomenon.

MR. W. G. HOLTZ.[7]—In our work in the Bureau of Reclamation we have experienced some rather sad results in the past on some foundations in which montmorillonite clays were present, and consequently we have become very conscious of recognizing these clays prior to design and construction.

We have developed several very simple index tests to identify the montmorillonite clays and other types of swelling clays. These are the free-swell, and staining tests. We also have good correlations between swelling properties and the Plasticity Index and the shrinkage limit values of soils.

MR. T. WILLIAM LAMBE (*author's closure*).—The author fully agrees with Mr. Gregg that at the present time the value of chemical and mineralogical properties lies in their aid in interpretating and understanding the results of standard engineering tests. However, the author does feel that in the far future it may be possible to make approximate predictions of the shear strength, permeability, compressibility, etc., of a soil from a complete understanding of the component parts and their geological history. Certainly the explanation of such phenomena as soil structure will be greatly aided by chemical and mineralogical studies.

As stated in the footnote on page 980 of the paper, one should not infer that quantitative analyses on natural soils will always be possible. For example, the thermal curves can be greatly affected by impurities. Also, as Mr. Kilcawley points out, the grain size, void ratio, etc., have effects on the thermal curves. It is not easy to study the relation of grain size to thermal curves, since it is difficult to maintain the same mineral composition for the different fractions. For instance it is possible that the finest size particles of a supposedly pure kaolinite may be montmorillonite.

The author is aware of contributions of such well-known scientists as Mr. Winterkorn in the field of soil stabilization. It was the purpose of the paper to indicate the procedure and significance of chemical and mineralogical properties to the common man of soil mechanics.

Finally the author would like to express his appreciation to the discussers of this paper. They have enhanced its value by bringing out points not well made and by presenting the other side of one of the author's opinions.

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[7] Head, Earth Materials Lab., U. S. Bureau of Reclamation, Denver, Colo.

SUBSURFACE EXPLORATIONS BY GEOPHYSICAL METHODS*

By E. Raymond Shepard[1]

Synopsis

The principles of both the seismic and the electrical resistivity methods of subsurface exploration are described and illustrated. The results of field tests, as made by the Corps of Engineers, show the methods to be relatively rapid and inexpensive in determining the depth of overburden as well as some of its physical properties. The seismic method has been particularly useful in the study of large dam sites, while the electrical retistivity method is more applicable to highway and levee construction. Methods of interpretation and analysis are described.

Although geophysical methods of subsurface exploration have been in common use for more than 20 yr., particularly in the search for petroleum, there has been some reluctance and delay in taking full advantage of these principles in the design and construction of engineering structures.

Of the numerous possible methods of geophysical exploration, only the electrical resistivity and the seismic methods have found application to the relatively shallow work involved in engineering problems. Some of the early attempts with the former method met with marked success while others proved to be decidedly disappointing. The difficulties and uncertainties inherent in the interpretation of electrical resistivity data and fundamental limitations of the methods to apply under all conditions are probably responsible for the reluctance on the part of some engineers and geologists to use this method and also the seismic method to the full extent of their possibilities.

A thorough understanding of the proper application and of the limitations of these methods is necessary for their most efficient and economical use. Under certain favorable conditions, as for example, on preliminary or reconnaissance investigations of dam sites, large savings in both time and money may be accomplished. In general, the character of the information desired will dictate the method of exploration to be used. Where specific information regarding the character of either rock or overburden is required, geophysical methods cannot often be used to advantage. However, where the thickness of overburden is to be determined or where a soil profile with respect to type of alluvial deposits or degrees of weathering is desired, geophysics can supply the answers with sufficient accuracy and reliability. Such methods are not wholly a substitute for the core drill and other established methods of exploration but rather an aid to them and often a guide by which the use of these slower and more costly methods can be limited to a practical minimum.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] U. S. Corps of Engineers, Washington, D. C.

A certain amount of drilling or test-pitting is desirable in any major geophysical program as an aid to interpretation of data and as a means of limiting the tests to areas wherein worth-while information can be obtained.

When intelligently used by experienced operators, these methods afford a relatively rapid and inexpensive means of exploring certain types of soil formations. Considerable literature on the subject is now available, and this should be consulted by those intending to employ the methods extensively. Seismic and electrical resistivity apparatus designed especially for engineering use are now commercially available and during recent years have been used extensively, particularly for preliminary surveys of dam sites.

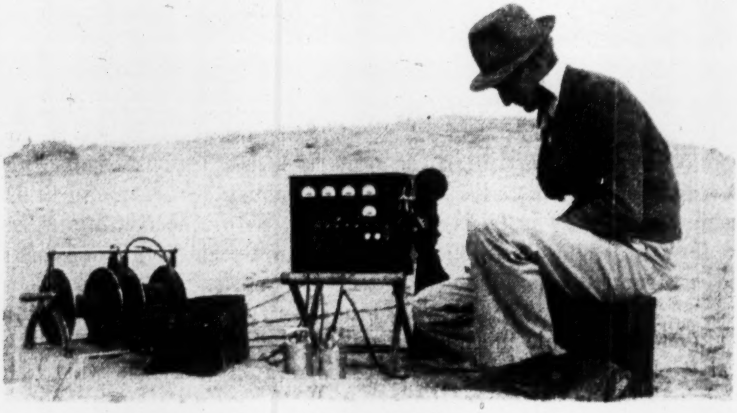

FIG. 1.—Portable Seismograph Used by Corps of Engineers for Subsurface Explorations.

THE SEISMIC METHOD OF SUBSURFACE EXPLORATION

Principle and Procedure:

The seismic method of exploration is based upon the fact that the velocity of wave propagation in the earth's crust differs greatly in different substances. Granular materials such as sand and gravel or plastic materials such as clay transmit wave disturbances, commonly called sound waves, at velocities of 600 to 6000 ft. per sec., while rigid materials like shale, sandstone, and crystalline rocks transmit such disturbances at 7000 to 20,000 ft. per sec. This wide range in velocities in different kinds of soils and rock provides a means of measuring directly the rigidity of subsurface materials, one of the properties with which the engineer is greatly concerned.

To what extent other physical properties such as bearing power and resistance to plastic flow can be determined from velocity measurements is not fully known. In a given region or under a given set of geologic conditions it is often found that certain formations can be identified and located by their characteristic velocities. As our knowledge of these matters increases and as our correlations between velocities and physical properties are extended, the seismograph as a geophysical tool will become more and more valuable.

Two methods of seismic exploration that are in common use are known respectively as reflection shooting and refraction shooting. These terms have the same significance in geophysics as they do in optics, the mathematical theory of the transmission of elastic waves through solids and liquids follows largely the well-known laws of optics. In reflection shooting, interpretations are based on waves that are reflected directly from different strata under investigation, while in refraction shooting it is the refracted waves that are studied. As reflection shooting is applicable only to relatively deep formations, the refraction technique is used exclusively for the shallow depths with which the engineer is concerned.

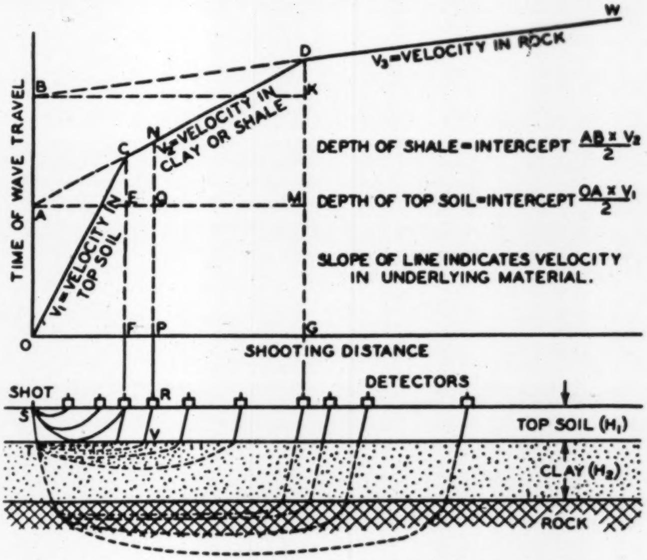
W
D
V_3=VELOCITY IN ROCK
B
K
V_2=VELOCITY IN CLAY OR SHALE
N
C
DEPTH OF SHALE=INTERCEPT $\frac{AB \times V_2}{2}$
E
O
M
A
DEPTH OF TOP SOIL=INTERCEPT $\frac{OA \times V_1}{2}$
TIME OF WAVE TRAVEL
V_1=VELOCITY IN TOP SOIL
SLOPE OF LINE INDICATES VELOCITY IN UNDERLYING MATERIAL.
F
P
G
O
SHOOTING DISTANCE
DETECTORS
SHOT
R
S
V
TOP SOIL (H_1)
T
CLAY (H_2)
ROCK

FIG. 2.—Time-Distance Curve, Soil Profile Determination.

The seismic apparatus, as used in refraction shooting, consists essentially of one or more detectors or geophones and an oscillograph recorder. The detectors are connected electrically with the oscillograph so that the time of the arrival at each detector of a wave disturbance can be photographically recorded. The disturbance is created by exploding a charge of dynamite in the ground at a known distance from the detectors. An electrical connection between the oscillograph and the dynamite records the shot instant. A time scale produced by an electrically driven tuning fork is recorded on the oscillograph film. A portable seismic outfit of the type used by the Corps of Engineers (**1, 2, 3**)[2] is shown in Fig. 1.

The usual practice in refraction shooting is to place three detectors on the ground in a line, at intervals of from 25 to 50 ft. Shots are then fired successively and at increasing distances along the detector line, beginning with 10 ft. from the center detector and extending the shooting distances by intervals of about 50 ft. to such lengths as may be required. A shooting distance of three to four times the depth to which information is desired is usually necessary. From the film records, the time of wave travel from each shot to each of the three detectors is read and the results plotted in the form of a time-distance graph, as shown in Fig. 2, from which a depth profile of the overburden with respect to velocity characteristics is derived.

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper; see p. 1009.

Depth Determinations:

Referring to Fig. 2, it will be seen that for a homogeneous material the time-distance relation from disturbances originating at the shot point, S, will be a straight line through the origin. This is evident from the fact that in such a medium the velocity of wave propagation is constant, or the time of travel is proportional to the shooting distance. It is also evident that the slope of such a graph is a measure of the velocity in the medium, since velocity is equal to distance divided by time.

When a layer of homogeneous soil is underlain by one of higher elastic properties, such as that designated as clay, there will be a critical shooting distance, such as OF, for which the time of travel through the upper medium is just equal to the time of travel over the longer path which penetrates the deeper and faster layer. At this critical distance there will be a break in the time-distance graph to a different slope, CD, which represents the velocity of wave propagation in the second medium. For shooting distances greater than OF, such as OP, the total time of travel, PN, over the course $STJR$ is made up of two parts; a constant time, PQ, and a time, QN. The latter is proportional to the shooting distance and represents the time of travel through the deeper medium from T to J. The constant time, PQ, must therefore be the time of travel from S to T, plus that from J to R, or through a distance $2H_1$, where H_1 is the thickness of the topsoil. Now, since distance is the product of velocity and time, $2H_1 = V_1 \times OA$, where V_1 is the velocity of wave propagation in the topsoil, and OA, the intercept on the time axis, is equal to PQ; or

$$H_1 = \frac{OA \times V_1}{2} \quad \ldots\ldots (1)$$

In like manner, when the critical shooting distance, OG, for the third, or rock, layer is reached, there will be another break in the graph to a new slope, DW, which represents the velocity in the rock stratum. Also, the intercept MK or AB represents the time of travel two ways through the clay stratum, whose thickness, H_2, is determined as follows:

$$H_2 = \frac{AB \times V_2}{2} \quad \ldots\ldots (2)$$

While these relations are based on the assumption of an ideal stratification of homogeneous materials, as depicted on Fig. 2, there is a striking similarity, as will be shown later, between the theoretical graph and many of those developed from actual field data.

The above equations are developed on the assumption that the path of the seismic wave is vertical from the shot point to the rock, thence along the rock to a point directly under the detector, and thence vertical to the detector. While this assumption gives satisfactory values for shallow depth determinations, it is preferable to use a more exact formula for the greater depths encountered in exploring locations for dams, reservoirs, and other large engineering structures.

Determination of Velocity in Rock and Slope of Interface:

When the surface of the rock or deeper zone is parallel to the ground surface, the velocity of wave propagation in this zone is determined from the slope of the graph as previously explained. When the interface is not parallel with the ground surface, it is necessary to shoot the line of detectors from opposite directions to obtain the true velocity in the deeper zone, and the data so obtained also can be used to determine the slope of the interface.

In Fig. 3, which applies only to gentle or moderate slopes, let

D_1 and D_2 be two detectors separated by a distance L,

V_1 = the velocity in the earth,

V_2 = the velocity in the rock,

T_d = the time difference in the arrival of the wave at each of two detectors,

and

S = the slope of the interface $= \frac{H_d}{L}$

When shooting down slope from A

$$T_d = \frac{L}{V_2} + \frac{H_d}{V_1}$$

$$= \frac{L}{V_2} + \frac{LS}{V_1} = \frac{LV_1 + LSV_2}{V_1 V_2}$$

The apparent velocity in the rock when shooting down slope will be

$$V_d = \frac{L}{T_d} = \frac{LV_1 V_2}{LV_1 + LSV_2} = \frac{V_1 V_2}{V_1 + SV_2}$$

or

$$S = \frac{V_1(V_2 - V_d)}{V_2 V_d} \dots\dots (3)$$

Likewise when shooting up slope from B

$$T_d = \frac{L}{V_2} = \frac{H_d}{V_1}$$

or

$$S = \frac{V_1(V_u - V_2)}{V_2 V_u} \dots\dots (4)$$

Combining Eqs. 3 and 4, we have

$$V_2 = \frac{2V_d V_u}{V_d + V_u} \dots\dots (5)$$

Relation of Shooting Distance to Depth of Exploration:

The shooting distance, L, required to reach a medium of velocity V_2 beneath an overburden of velocity V_1 and thickness H_1, is known as the critical distance and is shown as OF in Fig. 2. It can be seen that this is the shooting distance at which the time of wave travel, T, through the upper stratum is the same as that through the stratum of velocity V_2. Assuming rectilinear wave travel, this relation is expressed mathematically as follows:

$$T = \frac{L}{V_1} = \frac{L}{V_2} + \frac{2H_1}{V_1}$$

or

$$H_1 = \frac{L}{2}\left(1 - \frac{V_1}{V_2}\right) \dots\dots (6)$$

When the velocity ratio $\frac{V_1}{V_2}$ is relatively small, as for example 0.2, H_1 will be 0.4 L. This means that the critical distance at which the deep wave will overtake the wave in the overburden will be $2.5H_1$. If the velocity ratio is relatively high, as in till of 6000 ft. per sec., and rock of 10,000 ft. per sec., H_1 will be 0.2 L or L will equal $5H_1$. As it is desirable for confirmation to have at least two shots showing rock velocities, these estimated shooting distances should, in field practice, be somewhat exceeded in exploring to a predetermined depth.

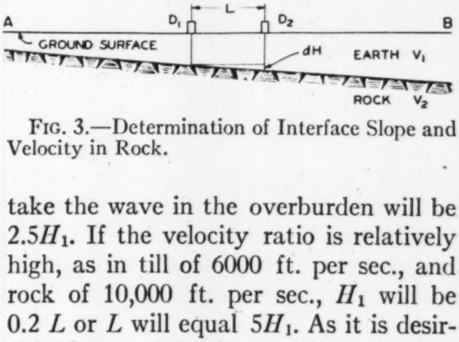


FIG. 3.—Determination of Interface Slope and Velocity in Rock.

Velocity Characteristics in Different Materials:

As all seismic interpretations are based on observed velocities, it is important to inquire into the many properties and factors which determine the velocity characteristics of subsurface materials. In general, it may be said that the velocity of wave propagation in nonconsolidated materials is low and that in consolidated materials it is high. However, when we consider that there is no sharp line of demarcation between these two classes and that velocities are affected by many other factors such as texture, moisture content, air voids, and compaction, there is little wonder that we find velocities ranging all the way from a minimum of about 600 ft. per sec. in light, dry topsoils to some 20,000 ft. per sec. in crystalline rocks.

The effect of moisture on the velocity in different materials is not fully known or understood, although moisture is known to be a major factor. It is often possible to determine the elevation of the water table in silty or sandy soil by an abrupt change in velocity from normally low values in the upper strata to values of 5000 to 6000 ft. per sec. Such an abrupt change in velocity might easily lead to a false interpretation unless the cause of the higher velocity is definitely known.

While there is little chance of making a serious error in interpreting either very low or very high velocities, there is a wide band of velocities ranging from about 2000 to 8000 ft. per sec. which are often difficult to interpret without correlating data from the particular location in question. Velocities within the range mentioned occur in such a large number of different subsurface materials and formations that it is not possible to associate any particular material with a given velocity. Silt, sand, loam, muck, and other similar re-deposited materials exhibit low velocities of 600 to 1600 ft. per sec., while in well-compacted clays and gravels, velocities range from 3000 to 6000 ft. per sec. In shales, sandstones, hardpan, and cemented gravel, velocities may be as high as 5000 to 8000 ft. per sec. When it comes to fractured and disintegrated rock, it is unsafe to place any limits on the velocities which may occur. Very low velocities, comparable to those in silt and sand, have been observed in a mass of loose rock and boulders which contained little or no earth but in which there was no continuity of structure. In native rock in place, but weathered, seamed and fractured, velocities usually range from 3000 ft. per sec. up. It requires only slight seaming to reduce velocities in crystalline rocks from 18,000 to 10,000 ft. per sec.

Upon undertaking work in a new or unknown area, it is always desirable to look for some correlating data such as wells, road cuts, test pits or drilling logs. One or two test pits or drill tests are often sufficient to give validity to a large number of seismic tests.

Applicability and Limitations:

The seismic method of exploration is not equally applicable to all types of formations, and it is important to know its limitations so that its use may be restricted to those conditions where useful and reliable information can be obtained. It can be used successfully in most localities, although regional geology has a pronounced effect on the accuracy and ease of interpretation. Ideal conditions are present when the surface of the rock is hard and unweathered, with little or no jointing or fracturing, as prevail in crystalline rock, sandstone, limestone or well indurated shale. Such conditions exist in most of New England and the Middle Atlantic states, in portions of the central area of the country, and in much of the Rocky Mountain and Pacific Coast territories. At even the most favorable site, however, local conditions may be encountered which will act adversely because of weathering of the rock. Where rock is badly weathered and the overburden is stony, it may be virtually impossible to distinguish between the two. Likewise, where well-compacted glacial till overlies a jointed or weathered rock surface, it is difficult to be certain of the location of the rock surface.

The method is particularly adapted to preliminary or reconnaissance surveys of dam sites. At many locations, a relatively small amount of work has eliminated possible dam sites from further consideration by showing the absence of sound rock needed for foundation support. Depths of gravel deposits and alluvial fills are determined with good accuracy and pre-glacial valleys and gorges outlined. In the South Atlantic Division through Virginia and the Carolinas, good results are obtained in the valley floors where overburden depths are readily determined. On the abutments, results are less reliable because of the highly selective weathering of the rock and the difficulty of determining the quality of weathered and fractured rock by velocity measurements.

The method has found useful application in the limestone region of Kentucky, Tennessee, and Indiana, where deep fills of alluvium are characteristic of the valleys. Here the primary use of the seismic method is in piloting the drill to the most economical sites. Generally, the location of a site depends upon the presence of a buried rock terrace or bench upon which a spillway, lock, or outlet structure may be founded.

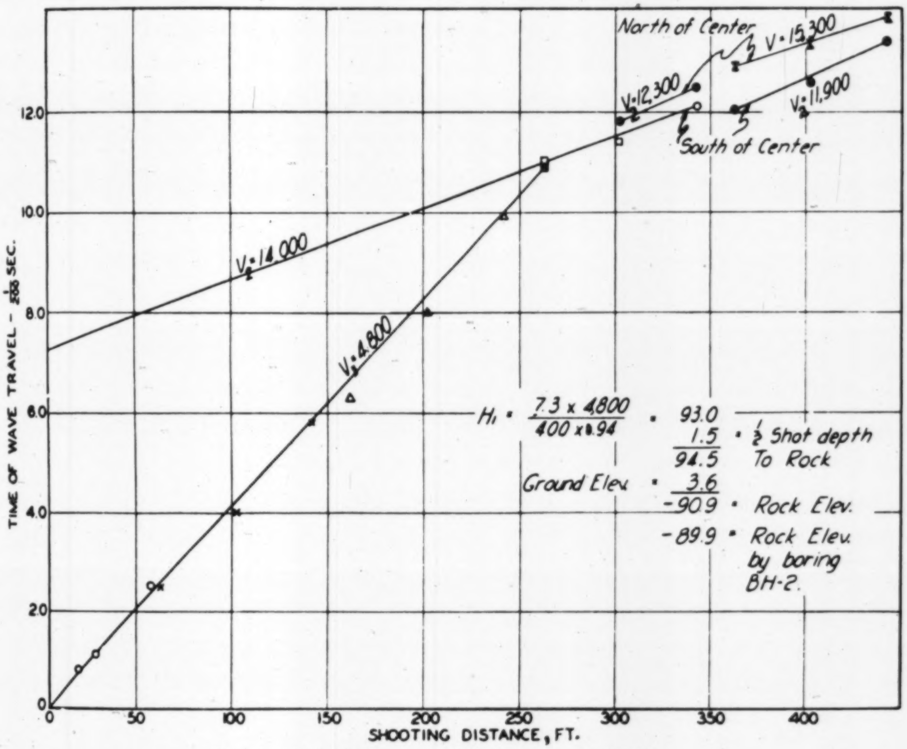


FIG. 4.—Seismic Record Along Connecticut River.

NOTE.—The various symbols on the curves represent plotted points obtained from different shots.

In limestone regions where solution channels, caverns, pinnacles and such irregularities occur, the method is not well adapted because of its inability to

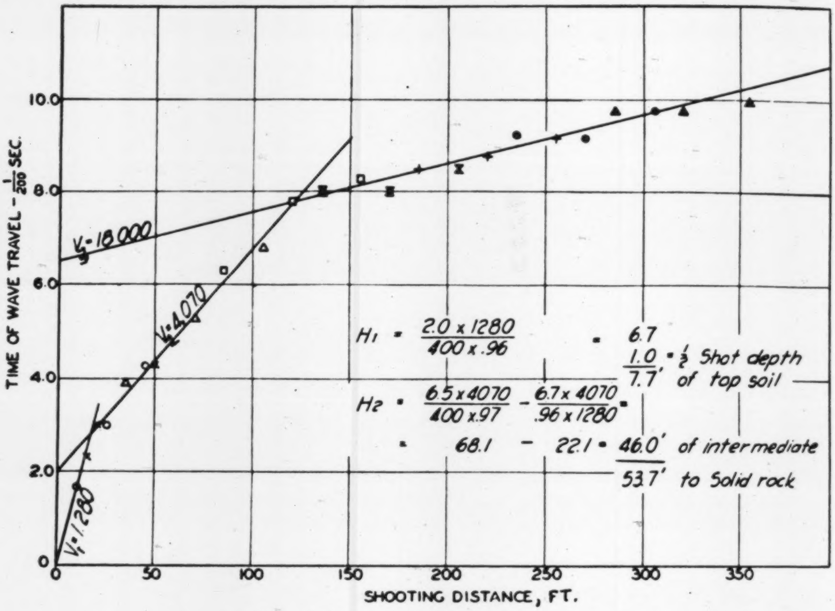


FIG. 5.—Seismic Record Along Olentangy River, Ohio.

NOTE.—The various symbols on the curves represent plotted points obtained from different shots.

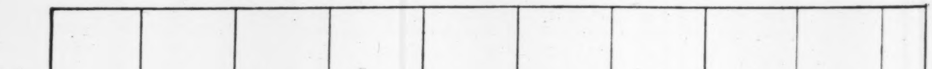


FIG. 6.—Seismic Record at Whitney Point, New York.

NOTE.—The various symbols on the curves represent plotted points obtained from different shots.

determine depths at a specific location or to obtain velocity profiles except where the velocity increases with depth. In such areas the average depth to the top of hard rock can be determined but the presence of minor anomalies is not easily disclosed.

The most usual problem for which the Corps of Engineers has found the seismic method of exploration applicable is that of determining the depth of overburden and the extent of rock weathering on proposed dam sites. In the river bottoms the depth of the alluvial deposits is desired, while on the abutments the depth of the overburden as well as the depth to firm rock is required. It is also important to determine the elevation of the top of rock at various possible spillway saddles. Where alternate dam sites are proposed it is often possible to eliminate one or more by the exploration of a relatively few seismic lines. In this way an accurate topographic survey of all possible sites may be deferred until the most suitable site has been selected. When a site is finally selected, the location and elevation of each line may then be determined.

Best results are obtained by laying out the seismic lines parallel to the river in the flood plain and along contours on the abutments. Generally this assures a more uniform overburden and depth to rock along the seismic line than if it is laid normal to the river.

Typical Examples of Field Operations:

A few typical graphs prepared from actual field operations will serve to illustrate the application of the seismograph to a variety of formations. The symbols on these graphs have the same significance as those in Fig. 2.

The simplest exploration problem to which the seismograph is applicable, is that of determining the thickness of sedimentary deposits over a relatively flat rock floor. Where this condition exists in a simple and ideal form, it is usually possible to obtain remarkably accurate and reliable results. Illustrative of this condition is the graph shown in Fig. 4, which is the result of measurements made along the Connecticut River near Hartford. The symbols in conditions in this area are particularly favorable for seismic exploration as the overburden is composed almost entirely of a homogeneous clay which transmits the seismic waves at a velocity of 4800 to 5300 ft. per sec. Records were obtained along the shore line of the river where in most places a few feet of silt overlies a dense blue clay.

Subsequent to the seismic measurements along the Connecticut River, a number of borings were made. The correlations between the two methods of test were generally satisfactory and were remarkably good at this location, as shown in the data in Fig. 4.

Figure 5 is given as a classical example of a three-layer condition and one in which the depth calculation is definite and straightforward.

The graph shown in Fig. 6 was made from seismic tests at Whitney Point, N. Y., where drilling logs provided an accurate check on the geophysical tests. In spite of the complex overburden present, a remarkably accurate depth to bedrock was predicted before the drilling records were disclosed.

Time and Costs:

Costs of seismic explorations, obviously, will vary over a considerable range, depending upon a variety of factors, including size of field party, character of terrain, amount of travel, accessibility of sites, and whether men are on per diem subsistence. On preliminary surveys, it is usually possible to shoot from two to five lines per day, or a probable average of three. At an estimated cost of $150 per day for a seismic party, this amounts to a round figure of $50 per line.

THE ELECTRICAL RESISTIVITY METHOD OF SUBSURFACE EXPLORATION

Principle and Procedure:

Subsurface exploration by the electrical resistivity method is accomplished by measuring at the ground surface changes in the electrical resistivity of the soil. This property of the soil, which varies inversely with the total amount of ionized salts present, is useful in exploration studies only so far as the physical properties of soils and rock can be related to it. As such relations are fortuitous, they cannot be expected to exist generally. However, under favorable conditions it is possible by measuring soil resisitivities to determine depths to interfaces or changes in underground conditions. As solid rock usually contains much less soluble salts than is present in soil, it is often possible to determine soil depths by this method. Similarly, differentiation can often be made between clean gravel or sand and that containing a relatively large amount of fine material.

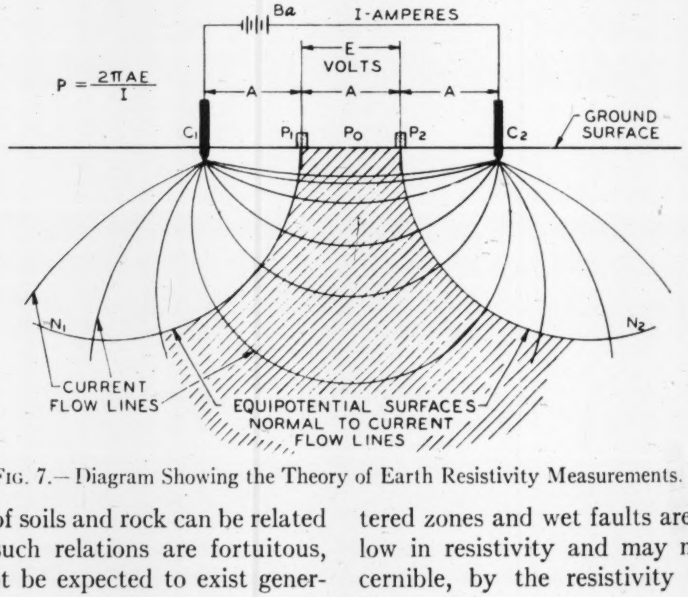


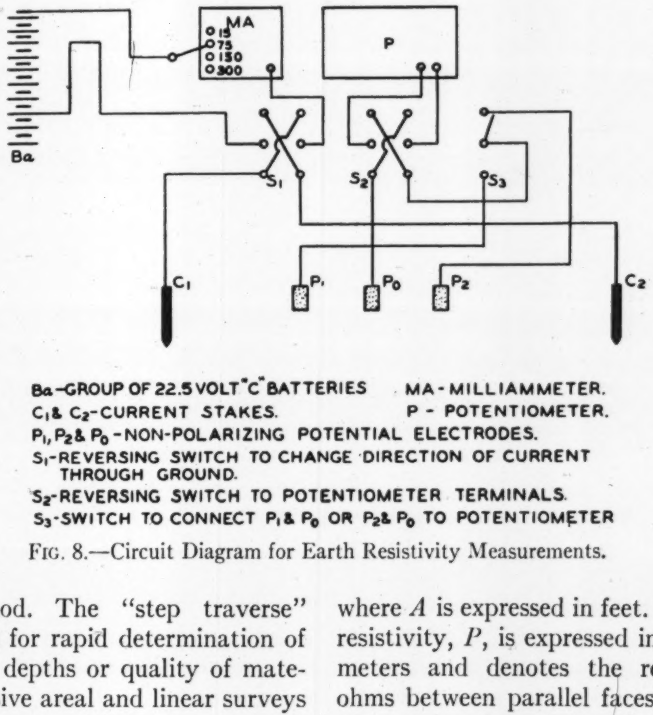
FIG. 7.—Diagram Showing the Theory of Earth Resistivity Measurements.

The method is not as accurate or reliable as the seismic method for determining overburden depths because some kinds of overburden exhibit as great or greater electrical resistivities as the underlying rock. If a rock is very dense, it is evident that the amount of moisture it contains and, therefore, the amount of soluble salts present, is exceedingly small and that its electrical resistivity is therefore, very high. This is true of rocks like granite, gneiss, marble, and of all metamorphosed or compact rocks, where only a limited number of open spaces or pores exist. Rocks with a high water content, like clays, marls, soft limestones, shattered zones and wet faults are relatively low in resistivity and may not be discernible, by the resistivity test, from the overlying strata.

The method has met with considerable success in outlining shallow areas of relatively clean and pervious coarse materials suitable for road surfacing and other purposes and in otherwise determining variations in overburden with respect to both vertical and areal distribution. It is more applicable to very shallow determinations, on which abrupt changes in observational data are frequently obtained, than on deep work, where interpretations are usually difficult and indefinite.

For shallow work it is more rapid and somewhat less costly than the seismic method, while for depths in the range of 100 ft., the time required in the two methods is about the same.

Several electrode configurations have been used for making earth resistivity determinations, but the one in most common use and used by the Corps of Engineers is the so-called Wenner, or 4-electrode, method. The "step traverse" method used for rapid determination of comparative depths or quality of material in extensive areal and linear surveys has been found useful in the study of levee design and construction and the investigation of alluvial deposits with respect to grain size.



MA
15
75
150
300
P
Ba
S_1
S_2
S_3
C_1
P_1
P_0
P_2
C_2
Ba–GROUP OF 22.5 VOLT "C" BATTERIES
MA - MILLIAMMETER.
C_1 & C_2–CURRENT STAKES.
P - POTENTIOMETER.
P_1, P_2 & P_0 -NON-POLARIZING POTENTIAL ELECTRODES.
S_1-REVERSING SWITCH TO CHANGE DIRECTION OF CURRENT THROUGH GROUND.
S_2-REVERSING SWITCH TO POTENTIOMETER TERMINALS.
S_3-SWITCH TO CONNECT P_1 & P_0 OR P_2 & P_0 TO POTENTIOMETER

FIG. 8.—Circuit Diagram for Earth Resistivity Measurements.

The principle underlying electrical resistivity measurements by the 4-electrode method is illustrated in Fig. 7. An electric current, I, is caused to flow through the earth between two electrodes, C_1 and C_2. Measurement is then made of the potential drop, E, between two intermediate electrodes, P_1 and P_2, placed in line between C_1 and C_2, and dividing the distance C_1, C_2 into three equal parts, A, termed the electrode interval.

In 1915 Wenner (4) showed that with this 4-electrode arrangement the specific resistivity of a homogeneous medium is given by the equation

$$P = \frac{191\pi AE}{I} \quad \ldots\ldots\ldots (7)$$

where A is expressed in feet. The specific resistivity, P, is expressed in ohm-centimeters and denotes the resistance in ohms between parallel faces of a centimeter cube of the material.

If the medium is not homogeneous, the indicated resistivity, P_a, termed the apparent resistivity, represents an average specific resistivity of the material bounded by the equipotential surfaces P_1N_1 and P_2N_2, but its value is determined largely by the properties of the material within a depth equal to A and only slightly by the materials at a relatively great depth.

Now, if values of apparent resistivities are obtained for various electrode intervals, and if these are plotted as ordinates against corresponding values of A as abscissas, the inflections in the resulting curve will indicate in a general way the vertical variations in the specific resistivity of the soil. Methods of interpreting such curves with respect to depths of discontinuities are discussed in a following section.

Apparatus:

Several types of electrical resistivity instruments are in common use, all of which are designed to eliminate or compensate for stray current and potential effects. The essential features of a simple direct-current type is illustrated in Fig. 8. It consists of a dry battery of variable voltage; a milliammeter having several ranges; a potentiometer for measuring voltages between the potential electrodes; two reversing switches; five electrodes, three of which are of the non-polarizing type designed to eliminate galvanic potentials; and suitable wires for connecting the movable electrodes to the stationary apparatus. The middle electrode was suggested by Lee (5) of the Bureau of Mines, its purpose being to determine slopes or unsymmetrical conditions along the test line by making independent voltage measurements on either side of the center. The non-polarizing electrode consists of a copper plate or coil of wire submerged in a concentrated solution of copper sulfate in an unglazed porous porcelain cup.

To eliminate the effect of any stray ground current of a constant and unvarying character, readings are taken with the test current flowing through the ground, first in one direction and then in the other, the reversing switch, S, being used to change direction of the current. Potential drop readings are taken between P_1 and P_2 and, if desired, between P_1 and P_0 and between P_2 and P_0 for both directions of the current. For each value of the electrode interval, A, the average value of E and I, respectively, is substituted in Eq. 7 and the corresponding apparent resistivities computed. From these figures the desired graph is derived. In practice, it has been found convenient to expand the electrode interval by increments of 2 or 3 ft. up to about 20 ft. and thereafter by increments of 5 ft. For great depths, the increment may be still further increased. The effects of fluctuating stray potentials, such as those caused by grounded street railway systems, are not entirely eliminated in the direct-current apparatus, as the magnitude of such potentials may change during the interval of taking the double or reverse readings. Where such conditions exist, it is desirable to repeat the measurements several times for each electrode setting.

Another method of eliminating stray and galvanic potentials is by the use of alternating or periodically reversed current. A hand-driven shaft bearing two reversing commutators accomplishes the same purpose as the two reversing switches shown in Fig. 8, the frequency being about 30 per sec. This type of apparatus, in use by the Corps of Engineers, was first developed by the National Bureau of Standards and used for the study of stray current corrosion of underground piping systems. It was known as the McCollum (6) Earth Current Meter. Later, Gish and Rooney (7), of the Department of Terrestrial Magnetism, Carnegie Institute, improved and enlarged the commutator, inserted a condenser in the potential circuit to reduce stray and galvanic effects still further, and made other minor improvements. As now used for electrical resistivity measurements in soils, it is known as the Gish-Rooney method. Apparatus used by the Corps of Engineers is illustrated in Fig. 9.

Interpretation of Electrical Resistivity Data:

The interpretation of electrical resistivity data is not as simple and direct a procedure as that for seismic data, where discontinuities are indicated by abrupt changes in observed velocities. Such rational methods of interpretation as have been developed are based on the assumption that the soil mantle is composed of homogeneous and isotropic layers, each having a definite electrical resistivity. The layers are assumed to be parallel to the ground surface and separated from each other by flat and parallel interfaces. As such layering rarely occurs in nature the interpretative methods applicable to it have usually failed to give satisfactory correlations with drillings and excavations. As a result of this condition, many investigators have resorted to empirical methods of interpretation based, as a rule, on inflections and anomalies in the observational data. These methods are entirely without theoretical support, and their accuracy depends upon the relative values of the resistivities of the several layers and also upon the relative depths to the several interfaces. They are also subject to misinterpretation as a result of local surface irregularities in the soil and other disturbing influences.

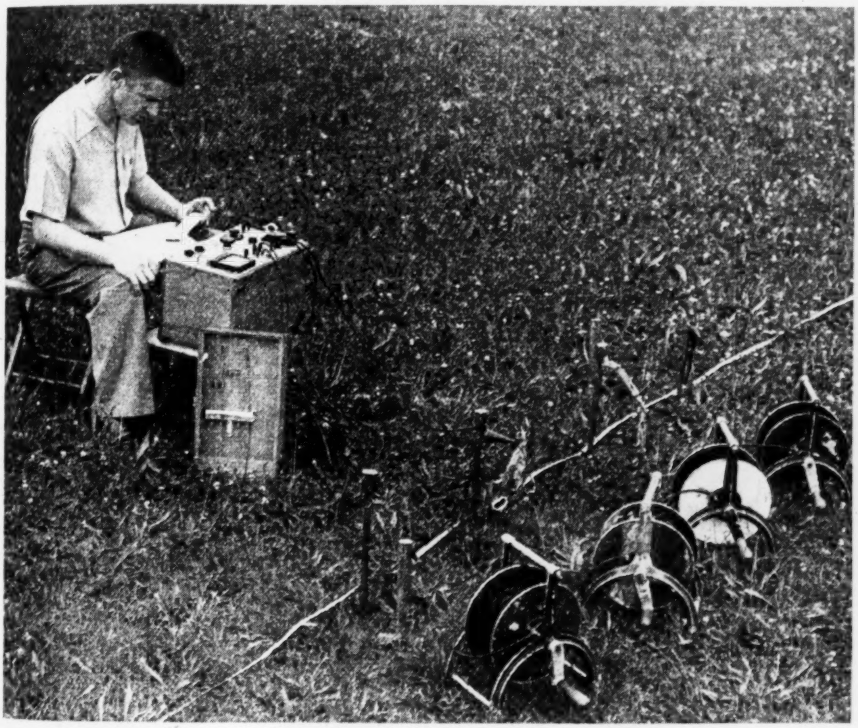


FIG. 9.—Resistivity Apparatus.

Even with these limitations and difficulties the empirical methods of interpretation are frequently the only ones applicable, and in a surprisingly large percentage of instances, particularly on shallow work, are giving reasonably satisfactory results.

Standard Curve Method of Interpretation:

In layered formations, as described above, 4-electrode resistivity data will assume graphical forms similar to those shown in Fig. 10. Where a layer of soil having a resistivity of P_1 is underlain by a layer of infinite thickness of resistivity, P_2, greater than P_1, the curve will be of the form shown in graph *a*. Where P_1 is greater than P_2 the curve will take the form shown in graph *b*, and where three-layer formations exist, the curves will often be as indicated in graphs *c* and *d*. In all instances the graph will assume a form such that it is tangent at its origin to the value P_1, the resistivity of the top layer, and also ultimately asymptotic to the value P_n, the resistivity of the deepest layer. In two-layer formations, such as those indicated in graphs *a* and *b*, Fig. 10, the shape of the curve affords a rough measure of the thickness of the top layer, as the steepness of the curve is inversely proportional to that thickness. While this is a help in estimating such thickness, it by no means provides a definite or reliable measure of the value sought.

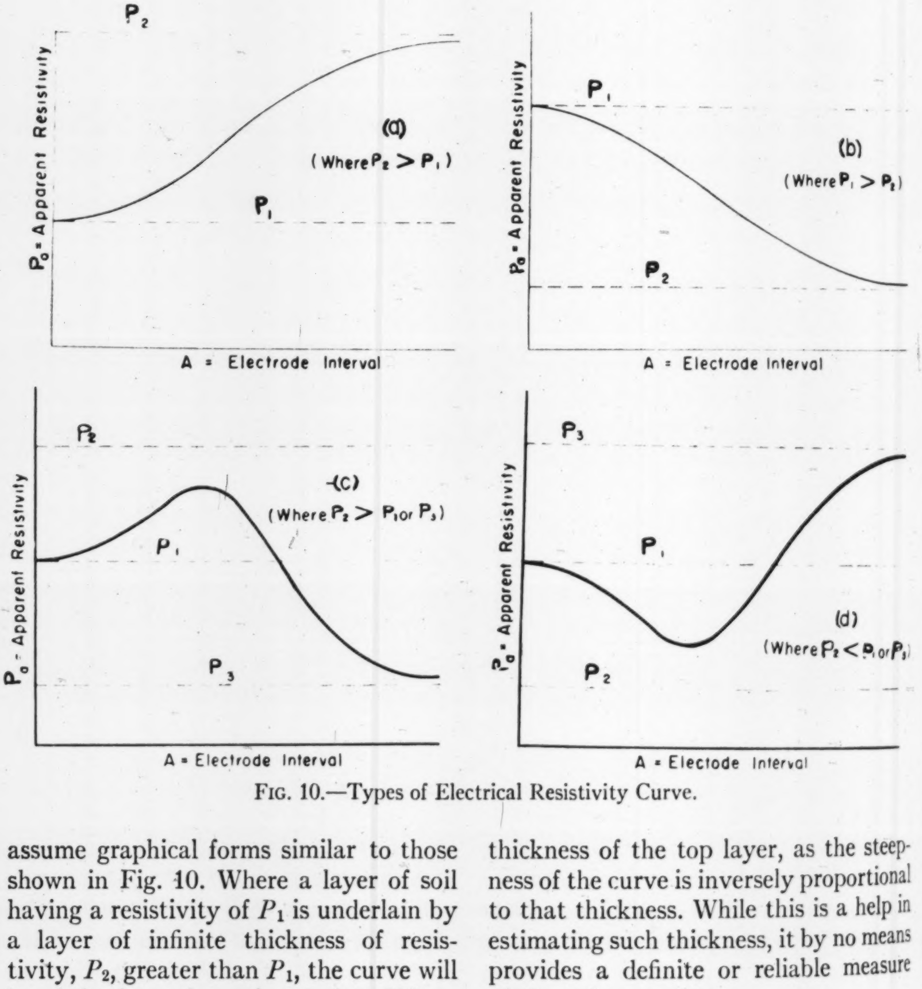


FIG. 10.—Types of Electrical Resistivity Curve.

In three-layer formations of the types represented in graphs *c* and *d*, Fig. 10, the value of *A* at which the peak of the curve occurs, as shown in graph *c*, or the value of *A* at which the valley occurs, as shown in graph *d*, often indicates with a fair degree of accuracy the depth to the third layer. This is what is known as the "Inflection Method" of interpretation.

It is possible to calculate theoretical values of apparent resistivities for two- and three-layer formations for given values of A, in the 4-electrode configuration. If, then, a match can be found between a field curve and a theoretically computed curve, it may be assumed that the field curve represents the same depth and resistivity ratios as those from which the standard curve was derived. This method of interpretation is referred to as the "Standard Curve Method."

Such theoretical curves have been computed for a few combinations of relative resistivities and depths. Roman (8) has made such calculations for a number of two-layer formations and Wetzel and McMurry (9) have computed values for 102 three-layer combinations, embracing 34 different ratios of resistivities, 3 depth ratios, and 10 values of the electrode interval.

Each of the 34 families of curves represents a given ratio of the three assumed resistivities and the following assumed depth ratios, 2 to 8, 4 to 8, and 6 to 8. In this form the curves are not suitable for matching with field curves because of scale differences. If, however, both the standard curves and the field curve are plotted on similar log-log paper, scale differences appear only as an additive factor and are taken care of by simply shifting the graph sheets laterally or vertically over each other to bring the two curves into coincidence. When a match is found, the depth to the third layer in the field is indicated by the abscissa reading on that curve which coincides with 8 on the standard curve. Likewise, the depth of the first layer is indicated by the first depth marker on the standard curve.

Inflection Method:

As an apparent resistivity, determined by the 4-electrode configuration, is a rough measure of the average resistivity to a depth equal to the electrode interval, some investigators have made a practice of taking electrode intervals at which breaks or inflections in the curve occur, as indicating boundaries of earth layers. Although, as previously explained, this method of interpretation is neither theoretically sound nor generally applicable, there are numerous conditions under which it provides a very simple and direct approximate solution to the problem.

Moore's Method:

Moore (10), of the Public Roads Administration, has developed a modification of the inflection method which, although without theoretical basis, has enabled him to obtain some remarkably accurate correlations between field data and actual depths as determined by drillings and excavations. The method consists of plotting a cumulative curve of values obtained by successive additions of the apparent resistivities. The greatly reduced scale required for plotting the cumulative values serves to minimize the effect of purely local surface anomalies and errors of measurement. The point of intersection of tangents drawn to intersect at zones of maximum curvature in the cumulative curve indicates the depth to the boundary in question. Moore has found that some types of smoothly rounded curves often obtained in the field, and to which neither the inflection nor the standard curve method of interpretation is applicable, appear to be susceptible to rather accurate analysis by his method.

The method must be used with great caution as it is possible to draw an infinite number of tangents to the type of cumulative curves usually encountered.

If the depth in question is known, it is always easy to find two tangents which will so intersect as to give what appears to be the correct solution. However, in many instances the latitude in selecting tangents is rather limited, thus permitting of a nearly unique solution. Moore, himself, has had considerable success with the method on shallow work. Experience and familiarity with the method should enable the investigator to know when to use it in lieu of, or in combination with, other methods of interpretation.

The Step Traverse:

The step traverse is an application of the 4-electrode method for the purpose of determining areal or lateral variations in electrical resistivity rather than depth profiles as previously described. A constant electrode interval is used, and measurements are repeated along a given course by advancing the 4-electrode configuration by a constant increment. The usual practice is to move it each time a distance equal to the electrode interval by advancing the rear electrode ahead of the leading electrode. This procedure discloses any major changes in the formation along the line of test within a depth equal to the electrode interval. It does not yield specific information on the materials present or the thickness of deposits, but by its use an intelligent spotting of drill holes may be made. It gives also an approximate method of interpolating between drill holes, also considerable assurance that abnormal conditions are not overlooked during the testing program.

The method is particularly applicable to a study of alluvial deposits with respect to grain size, where the object is to outline borrow areas of coarse sands and gravel. It also has application to levee design where a knowledge of variations in the thickness and quality of an impervious blanket is the information desired. In all such investigations, an electrode interval, usually 15 to 50 ft., is selected which is approximately equal to the depth to which information is desired. With this fixed electrode interval, variations in the observed apparent resistivity along a traverse or over any desired area will usually be a measure of the fineness of the material; or if the electrode interval is comparable to the depth to firm rock, the variations in resistivity may indicate variations in overburden depths.

The most satisfactory results are obtained from the traversing method if the electrode interval is equal to or slightly exceeds the thickness of the bed under investigation. This can be determined by running a few preliminary depth profiles over the area. The Gish-Rooney type of apparatus shown in Fig. 9 is provided with a special switch for progressively rotating electrode positions for convenient step traverse measurements.

Costs:

As in seismic work, the cost of exploration by the electrical resistivity method will depend upon a number of factors. A normal party consists of 1 engineer, 1 recorder, and 2 laborers. This is the minimum consistent with efficiency of operation. On very deep work, 4 laborers should be available for moving electrodes. In addition to the operator, who reads the instruments, the party should include a recorder and computer as it is desirable to compute and plot the data before leaving a location. This is done to avoid errors and also to fill in additional measurements at critical points of the graph. One car is usually sufficient for the party, and no supplies are required other than for maintenance of the apparatus.

Such a party as described should make

from 4 to 5 depth profiles per day to a depth of 100 ft. For depths of 40 to 50 ft., 12 to 15 depth profiles per day can be made. On traverse work, the linear distance that can be covered per day, usually 2000 to 4000 ft., will depend upon the electrode interval used.

As to comparative costs, it may be said that they are roughly one half those for equivalent seismic determinations.

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DISCUSSION

Mr. R. Woodward Moore[1] (*presented in written form*).—This paper by Mr. Shepard is of particular interest in that it again focuses our attention on two useful and practical methods of rapidly exploring the subsurface for hidden conditions which may aid or hinder a given construction program. The author has described the work of the Corps of Engineers with particular regard to refraction seismic tests and their application in preliminary surveys of proposed sites for large flood control dams. The writer would like to emphasize the usefulness of such methods of test in connection with smaller, less costly structures and with special regard to highway construction.

The Public Roads Administration has given a considerable amount of study since 1933 to the development of suitable portable apparatus and to the development of field procedures for the efficient application of these methods of test to highway problems. The resistivity test has been found to be of real value (1) in surveys for locating localized deposits of sand and gravel or of soils that would be of particular value for use in subgrade improvement or fill construction, (2) in the classification of excavation materials for use in slope design, and (3) in foundation studies for bridges. The refraction seismic test, on the other hand, although having little value in a search for sand and gravel or special soil types, has a very practical application in the classification of materials and in foundation exploration. Up to the present time ten states have used or are now planning the use of such methods of test in connection with highway construction. Active interest has been shown by representatives of many foreign countries as well.

Because of the ease with which men may be trained to operate the resistivity apparatus and the rapidity with which the resistivity tests can be made, we have found this method of exploring the subsurface to have particular value in preliminary surveys of proposed highway locations. The data from such surveys are of prime importance to proper slope design. Plans calling for solid rock slopes on a highway grading project will, in many instances, influence the contractor to submit a relatively high bid price for excavation regardless of whether or not he believes that solid rock is present. As a result, money has been expended in constructing our highways that could have been saved if the soil or weathered rock actually found in construction had been anticipated and the proper slope design had been made a part of the plans.

The hand augers ordinarily used in making a soils survey along a proposed roadway are easily stopped or blocked by boulders, etc., encountered below the ground surface, and much trouble has been experienced by those concerned with making such a survey in areas where stony soil and talus debris are found. Where obstructions are encountered, there can be no assurance that solid rock is not involved. Under such conditions the geophysical methods of test are useful since either the seismic or the resistivity test will indicate definitely the presence or absence of a continuous solid rock formation.

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[1] Highway Engineer, Public Roads Administration, Washington, D. C.

Personnel of the field survey party can be readily trained to operate the resistivity apparatus and will soon acquire the skill required to make tests to depths of 50 to 60 ft. at a rate of approximately one test every 20 min. in rough mountainous terrain. One or more miles of a projected right-of-way can be investigated in an 8-hr. day. As stated by the author, such rapid and relatively inexpensive tests can be used to considerable advantage in a preliminary survey of subsurface conditions. The information so obtained may be used as a guide in planning any program involving the use of direct methods of exploration, often making possible the elimination of drill holes or test pits over extended areas and allowing a concentration of such direct tests in localized areas where unusual conditions are indicated by the geophysical tests.

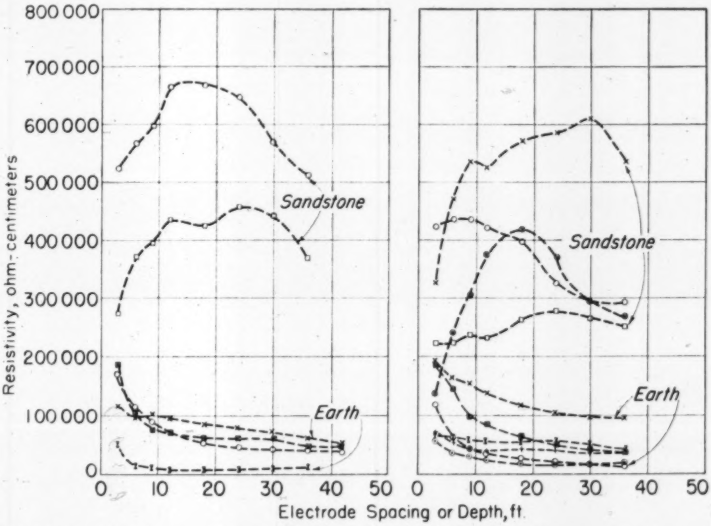

FIG. 11.—**Resistivity Calibration Curves (left) and Typical** Field Curves Obtained in the Ozark National Forest Near Russellville, Ark.

The author mentions, and it is again emphasized, that adequate calibration tests over known subsurface conditions are necessary for the successful interpretation of data obtained with either method of test. Such calibrations in the general locality through which a highway is expected to pass often result in data of such a definite character that they can be used with assurance in predicting the presence or absence of solid rock above the proposed grade line in a particular cut section. Typical calibration curves from resistivity tests, together with several typical field curves, are shown in the accompanying Fig. 11. The calibration curves, shown on the left, were used to evaluate some 118 field curves obtained over the major cuts on approximately 22 miles of a proposed roadway through the Ozark Mountains in Arkansas. The majority of field curves indicated that no rock would be encountered.

Only 12 working days were required for the survey party to obtain the field data for the entire 22 miles, with an average rate of one 60-ft. depth test every 20 to 30 min. Obviously where calibration data of the type shown are

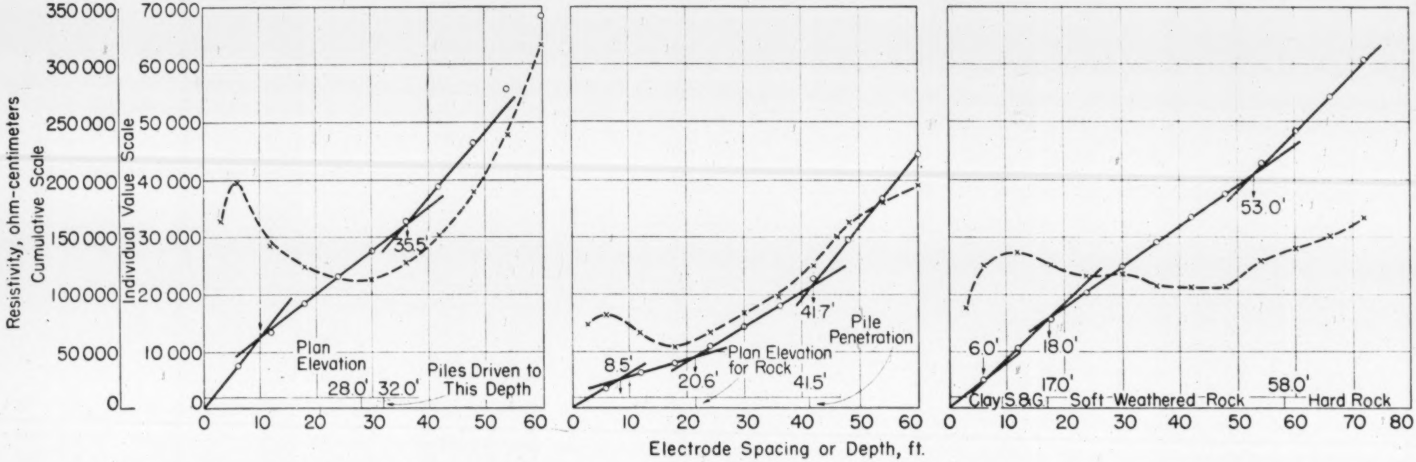

FIG. 12.—Earth Resistivity Tests at Flint River Crossings on U.S. 19 South of Thomaston, Ga., Locate Subsurface Rock for Bridge Foundation More Accurately Than Drill.

obtained, there is little likelihood of difficulty in properly interpreting the field curves. Where curves of the type labeled *earth* in Fig. 11 are obtained, there is little need for computing a depth factor for a particular test. The trend of the curve alone will be indicative of a soil formation existing to the full depth of the test.

As the author states, we have been quite successful in being able to predict depth of overburden to solid [illegible] with the cumulative or graphical integration method of analysis. The accompanying Fig. 12 shows three fairly typical examples of depth determinations made in connection with bridge foundation studies. These data, obtained during December, 1948, at a bridge recently constructed across the Flint River in southwest Georgia, indicate depth to solid rock more accurately than the direct methods of exploration which were used in a foundation study prior to the design of the bridge. One pier designed for a solid rock foundation actually had to be supported on piling driven to solid rock at an elevation some 20 ft. below the plan elevation for rock. Here is a striking example of the value of resistivity test data from preliminary explorations prior to any drilling program. The refraction seismic test likewise would have given a dependable indication of the general rock elevation but would have been somewhat more expensive and time-consuming. It has been our practice to obtain resistivity data as the basis for the subsurface survey, and to use the seismic test at a few locations to corroborate the indications of the faster resistivity tests. We use the seismic test also wherever, for any reason, the resistivity test has produced inconclusive data.

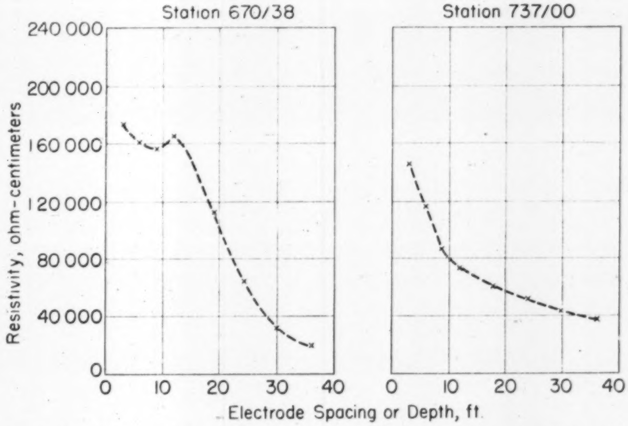

FIG. 13.—Resistivity Curves Obtained in Ozarks Showing a Possible Correlation Between Resistivity and Soils Classification.

Good Soil Indicated by Curve on Left. HRB Group Index 1 and 2.
Poor Soil Indicated by Curve on Right. HRB Group Index 14 and 15.

High resistance layers do not always constitute a barrier to the use of the resistivity method. In fact, it is often possible to penetrate such layers and detect the presence of shales or other materials which, although having lower electrical resistivity than the weathered and disturbed overburden, are nevertheless quite dense and require blasting for efficient removal. Such a condition was found in the vicinity of Harrisburg, Pa., where high-resistance materials overlying the shales are easily removed with heavy self-loading scrapers, while the low resistivity shales beneath must be blasted. The Pennsylvania Turnpike Commission has used resistivity methods of test for the past year in a subsurface survey of some 100 miles of a proposed extension of the Turnpike to Philadelphia.

Of particular interest to soils engineers is an indication that it may be possible to employ the resistivity test for differentiating, at least in a general way, between soil types. Figure 13 shows two curves obtained some miles apart on one of the Arkansas projects previously referred to, which suggest this possibility. The curve on the left indicates a material different from that existing at the location where the data on the right were obtained. Both curves were interpreted for earth excavation to grade, which in each case was at a depth of about 10 ft. at the centerline. Test pits dug several months later showed good soil to grade-line at Station 670 + 38 and very poor soil at Station 737 + 00. The sustained values of resistivity at approximately 160,000 ohm-cm. for the first four points in the curve shown on the left followed by a precipitant drop in resistivity suggest better material in the surface layer than that to be found at a depth of 12 to 18 feet below the surface. The immediate sharp drop in resistivity shown by the curve on the right, however, fails to indicate a surface layer of good soil and can be interpreted as indicating a relatively poor soil extending from the surface down to the full depth of the test. Calibration tests over known soil types of the immediate area would be required for comparison with the curves obtained in a field investigation. There has been no detailed investigation of this possible relationship between the resistivity of the soil and its classification; however, this is an important matter for further study because, if even general classification of soil materials by this means should prove practicable, another useful tool would be added to those available to the soils engineer.

MR. M. N. SINACORI[2]—The Bureau of Soil Mechanics of the New York State Department of Public Works owns both a seismograph and an electrical resistivity apparatus. Both of these pieces of equipment are being used to good advantage by our Senior Engineering Geologist, Mr. Paul H. Bird. They are generally used to supplement the information obtained from drill holes. The foundation correlation obtained between these two types of equipment, and the drill hole information, has generally been highly satisfactory, and because of it, we have been able to reduce the number of drill holes required to develop foundation conditions. In some cases wherein the general conditions of the area are known, the information obtained by either the seismic or electrical resistivity method is used without the benefit of correlation with drill holes.

The seismograph is generally used to determine the depth of overburden to top of rock, while the electrical resistivity apparatus has given satisfactory results in locating the depth to a gravel layer or the thickness of a gravel deposit.

In one instance, our geologist has used the electrical resistivity apparatus to determine the effective change in density of a waste dump fill due to rolling on the surface with a heavy pneumatic tired roller. All other factors remaining constant, an increase in the density is reflected by a corresponding decrease in the resistance to the flow of electricity. In this case, the change in resistance was measured to a depth of from 3 to 5 ft.

In general, we have found that the use of both the seismograph and the electrical resistivity apparatus has reduced the cost of our foundation exploration without visible sacrifice to the quality of the information obtained.

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[2] Associate Soils Engineer, New York Department of Public Works, Albany, N. Y.

MR. W. G. HOLTZ[3]—We have one seismic truck which we send out all over the West. We need more equipment, now, since we have obtained such good results with both the seismic and electric resistivity methods.

We are also using the electric resistivity method to locate deposits of riprap in the Missouri Valley at the present time. This is another application of the method.

MR. W. S. HOUSEL.[4]—We are using the resistivity method. Our work has just started in the last year, and we have no results to report at the present time.

We intend to use it in shallow work for the location of suitable deposits of local materials for use in embankment construction and projects of that nature.

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[3] Head, Earth Materials Lab., U.S. Bureau of Reclamation, Denver, Colo.

[4] Associate Professor of Civil Engineering, University of Michigan, and Research Consultant, Michigan State Highway Department, Ann Arbor, Mich.

STUDY ON MECHANICAL OSCILLATORS*

By R. K. Bernhard[1]

Synopsis

A mechanical oscillator to excite sinusoidal one- and two-dimensional vibrations has been developed which allows a continuous change of the resultant force vector in frequency, magnitude, direction, and action line while the oscillator is in operation. Analytical and graphical solutions are presented. The construction of such an oscillator, including an automatic electro-mechanical control is described and some fields of application are discussed.

By "Mechanical Oscillator" is meant a machine to produce periodically changing forces or moments or pure sinusoidal characteristics. Mechanical oscillators may comprise one or more masses, rotatable around the same or parallel shafts. All masses are supported eccentrically, thus producing centrifugal forces when rotating.

One-Mass Oscillators.—The resultant force vectors rotate. In order to excite unidirectional force vectors, special guides or epicyclic gear trains are necessary to eliminate any undesirable direction of the force vectors.

Two-Mass Oscillators.—Both masses rotate in opposite direction. The resultant force vectors are unidimensional. Hence force vectors in one fixed direction only, can be produced.

Three-Mass Oscillators.—The two outer masses rotate in the same direction, however opposite to the center mass. The resultant force vectors can be one or two dimensional. Direction and, in case the three masses rotate around parallel shafts, the action line of the resultant force vectors can be changed. Hence force vectors in any direction and action line are producable.

Five-and More-Mass Oscillators.—Multiple mass oscillators have essentially the same characteristics as three-mass oscillators.

Historical Development:

The first machine of the two-mass type was suggested in a report of the Indian Railway Bridge Stress Committee in 1921 (**1**).[2] Extensive tests with a two-mass oscillator were carried out by the North Eastern Railroad in England from 1924 to 1925 and published in the Report of the British Bridge Stress Committee in 1929 (**2**). This development was continued in 1927 by the German Railroads, reported for the first time in 1928 (**3**), and later extended into the field of soil dynamics by the German Society of Soil Mechanics (**4**). As far as the author knows, the first report on a three-mass oscillator was published by F. P. Ullrich in 1935 (**5**) in connection with earthquake resistance research. An oscillator to determine the dynamic characteristics of vibrating systems in general, that is in the structural field as well as for investigations of soils and highways, was developed in 1936 by the author (**6**). Since that time quite a number of different oscillators embodying various improvements have been built (7, 8).[3]

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] Professor of Engineering Mechanics, Rutgers University, New Brunswick, N. J.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1032.

An oscillator which includes features hitherto unpublished will be described in this report.

PURPOSE

The purpose of this mechanical oscillator is to excite:

1. Force or moment vectors of pure sinusoidal characteristic.
2. Force or moment vectors of constant magnitude regardless of the frequency.

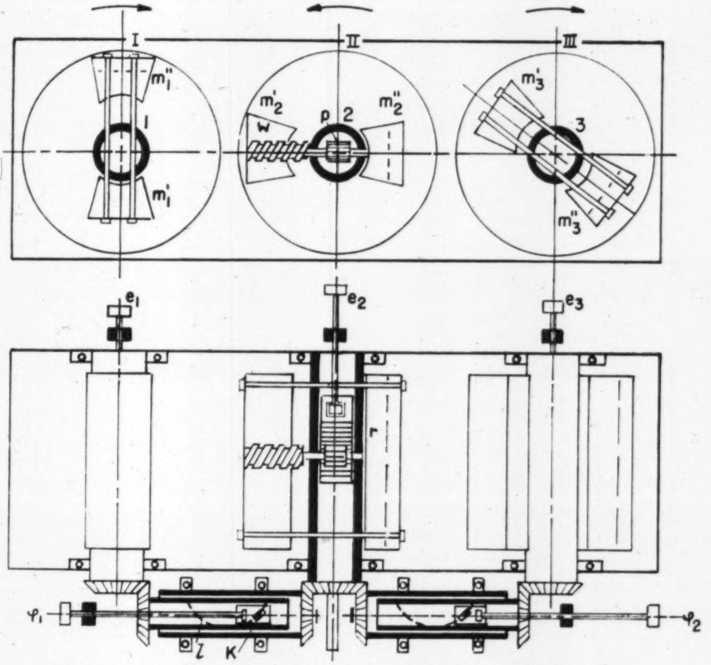

FIG. 1.—Mechanical Oscillator (U. S. Patent applied for).

I, II, and III: Mass Systems. 1, 2, and 3: Rotating Shafts. m_1, m_2, and m_3: Interchangeable Weights. Eccentricity Control: *w*, *p*, and *r* worm, pionion, and rack. *e* control knobs. Phase Control: *k* multiple key, *l* helical slot, φ control knobs.

3. Force vectors which can be changed continuously or periodically (a) in frequency, (b) in magnitude, (c) in direction, and (d) in action line.
4. One-dimensional (linear) or two-dimensional (circular or elliptic) force vectors.
5. Force or moment vectors in which all the above changes can be made independently of one another without changing the position of the oscillator and while the oscillator is in operation.

For special cases the force vectors may be made adjustable in such a way as to make the complete oscillator unit automotive. Finally the control of force or moment vectors must be automatic and remote.

To fulfill all these requirements a three-mass oscillator with an electromechanical servo-mechanism has been developed. The increase in cost for the servo-mechanism will be justified in all cases where the enhanced versatility of the oscillator can be used advantageously.

CONSTRUCTION

Mechanical Set-up:

Figures 1 to 4 show the developed

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[3] Designs for a three-mass and a five-mass oscillator have been developed by S. H. Fillion, Research Engineer, Waugh Equipment Co., New York, N. Y.

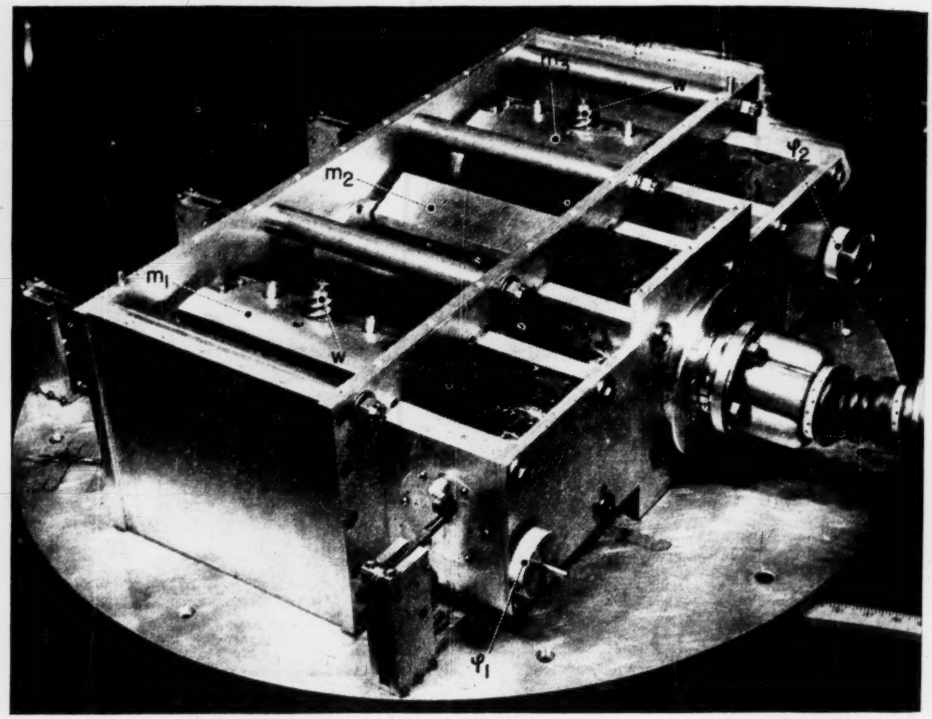


FIG. 2.—Mechanical Oscillator.

Top cover and Control motors removed. For letter symbols see Fig. 1.

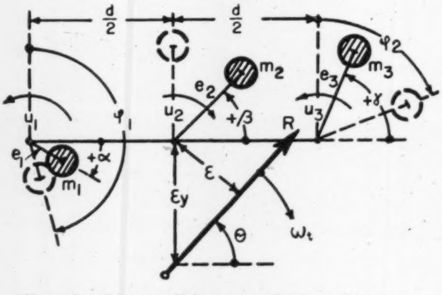


FIG. 3.—Vector Diagram of Mass System.

m_1 = left mass
m_2 = center mass
m_3 = right mass

e_1 = eccentricity of m_1
e_2 = eccentricity of m_2
e_3 = eccentricity of m_3

u_1 = unbalance: m_1e_1
u_2 = unbalance: m_2e_2
u_3 = unbalance: m_3e_3

$d/2$ = distances of center of rotation: $u_2 - u_1 = u_2 - u_3$

α = angle of e_1 with respect to horizontal
β = angle of e_2 with respect to horizontal
γ = angle of e_3 with respect to horizontal

R = resultant force vector

ϵ = eccentricity of R with respect to center of rotation of m_2

ϵ_y = eccentricity of R measured on vertical through center of rotation of m_2

φ_1 = phase angle between e_2 vertically upward and e_1
φ_2 = phase angle between e_2 vertically upward and e_3
ω_t = time angle
θ = phase angle of R with respect to the horizontal

oscillator built according to the above specifications.

The main reason for selecting an oscillator with three masses mounted on three parallel shafts is that any force in space can be resolved into a single force and a couple (Poinsot's theorem). The single force may be produced by the center mass, the couple by the two outer masses.

Hence the experimental machine (Fig. 1) consists essentially of three mass-systems (I, II, III) rotatable around three parallel shafts (1, 2, 3). All three systems rotate with the same angular velocity, either in the same direction or the two outer shafts (1 and 3) in opposite direction to the center shaft (2). Each mass-system consists of one or two interchangeable weights ($m'_1 m''_1 - m'_2 m''_2 - m'_3 m''_3$). The center of gravity of these weights with respect to the geometrical axis of the shafts as well as the phase angles of the weights m_1 m_3, with respect to the weights, m_2, can be altered continuously while the oscillator is operating. All eccentricity and phase shifts are completely independent of one another. The eccentricities can be varied by means of worm, *w*, rack, *r*, and pinion, *p*, drives; phase shifts can be made by means of multiple keys, *k*, guided in helical slots, *l*. Eccentricity and phase control units may be replaced by differential gears. When rotating the three mass systems, any eccentricity of the weights will produce centrifugal force or moment vectors.

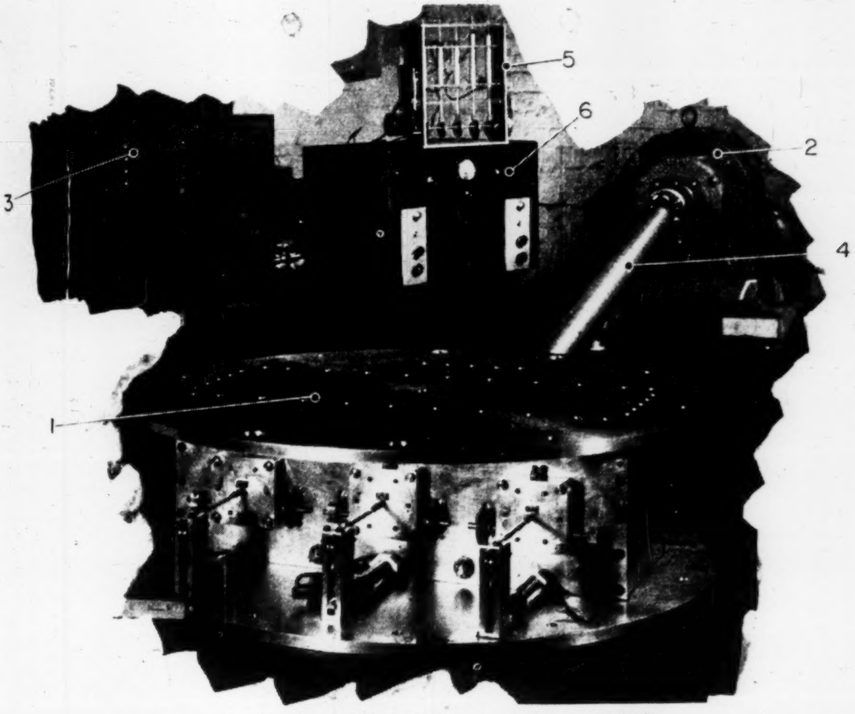


FIG. 4.—Mechanical Oscillator and Control Units.

1. Mechanical Oscillator 2. Main Driving Motor. 3. Electric Control for 2. 4. Shaft Connecting 1 and 2. 5. Camtroller Unit. 6. Electronic Control between 1 and 5.

Main Driving Motor:

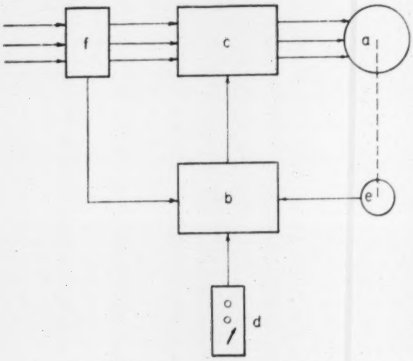


FIG. 5.—Block Diagram of Main Motor Control.

(*a*) Main Motor	(*d*) Start-Stop-Speed Control
(*b*) Electronic Control	(*e*) Pilot Generator
(*c*) Saturable Reactors	(*f*) Starting Switch

The main driving motor of the oscillator must have two special characteristics:

1. A continuously variable speed range from 0 to 3600 rpm. governing the operating frequency of the oscillator.
2. A constant speed, once the speed is selected, regardless of changes in torque.

The second characteristic is necessary in order to maintain a constant speed within the resonance range of the vibrating system. It is in this resonance range that the torque requirements may change substantially.

For the main driving motor (Fig. 5), a 5-hp., three-phase induction motor, *a*, with electronic speed control *b*, was chosen. Motor and control have been developed and built by Crocker Wheeler Division of Joshua Hendy Corp. Each phase contains one saturable reactor, *c*. Changing the saturation in these re-

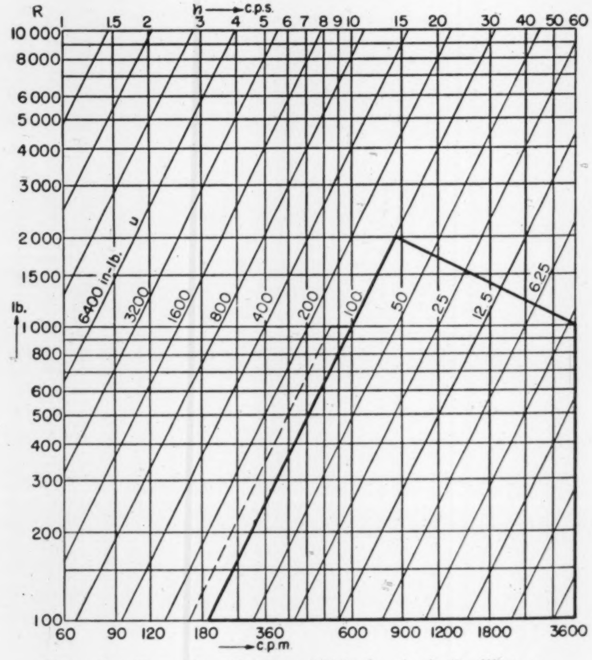
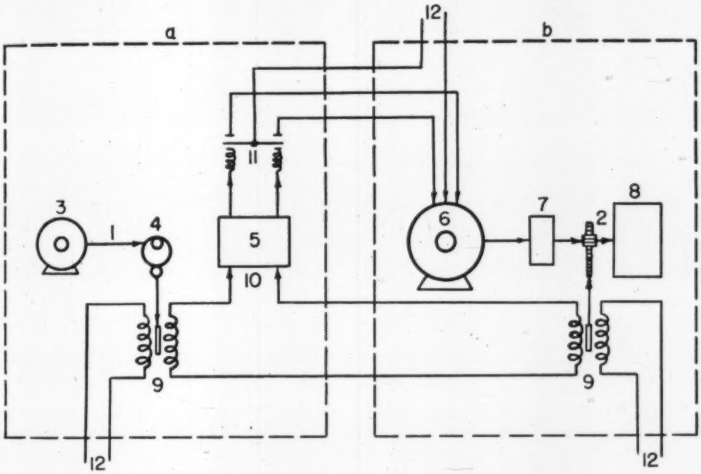


FIG. 6.—Capacity Chart of Mechanical Oscillators.

$$R = 0.1\,Un^2 \cos \omega t,$$

where:
R = centrifugal force vector in pounds,
U = unbalance in inch pounds,
n = number of revolutions of weights in cycles per second, and
ωt = time angle.

actors produces the required speed variation from 0 to 3600 rpm. The amount of saturation is controlled by a d-c. current, supplied from two thyratron tubes. A d-c. comparison voltage is obtained from the line via a vacuum tube rectifier and set manually by means of a small potentiometer, *d*. A pilot generator *e*, mounted on the shaft of the main motor, and a rectifier produce a second d-c. voltage which is proportional to the speed of the main motor. The difference (error) between these two voltages must be amplified. This amplified error voltage controls the firing of the two thyratrons and thus the choking effect of the reactors, which in turn governs the speed of the main motor.



(*a*) Control Stand.

(*b*) Oscillator.

FIG. 7.—Block Diagram of Electro-Mechanical Servo Mechanism.

1. Input shaft
2. Output shaft
3. Cam drive motor
4. Cam
5. Voltage amplifier
6. Servo motor
7. Worm gear drive
8. Load (to phase or eccentricity shafts)
9. Transducers (differential transformers)
10. Error voltage
11. Relays (forward, reverse, stop)
12. A-c. supply

For a set speed of the main motor a change in torque of ± 20 per cent produces a speed fluctuation of less than ± 1 per cent.

The connection between motor and oscillator consists of a 6-ft. long tubular shaft with universal joints at each end. The two joints are equipped with self-aligning needle bearings which permit the necessary length fluctuations. This rigid shaft prevents undesirable angular phase displacements in contrast to a flexible shaft connection.

Capacity:

The capacity of any mechanical oscillator is governed by the rotational speed of the masses and the magnitude of their unbalances, that is the product of weight times eccentricity.

Figure 6 shows a general capacity chart of mechanical oscillators; on the *Y*-axis the centrifugal force vectors (R in lb.), on the *X*-axis the frequencies (*n* in cycles per second and in cycles per minute) of these vectors are plotted. Due to the log-log scales the unbalances (*u* in in-lb.) appear as straight lines; the dark line enclosed area represents the capacity range of the developed oscillator.

This experimental oscillator is rated for a 2000-lb. resultant force vector at 14 cycles per second and a maximum frequency of 60 cycles per second. The total weight is approximately 250 lb.

Automatic Control:

The three eccentricity vectors (e_1, e_2, e_3) and the two phase angles ($\varphi_1\varphi_2$) of the rotating masses (Fig. 3) can be remotely controlled, independently and automatically, while the oscillator is operating, by means of five almost identical electromechanical servo-mechanisms. These mechanisms are able to follow any type of analytic function such as required for eccentricity and phase control. These functions are discussed later in detail.

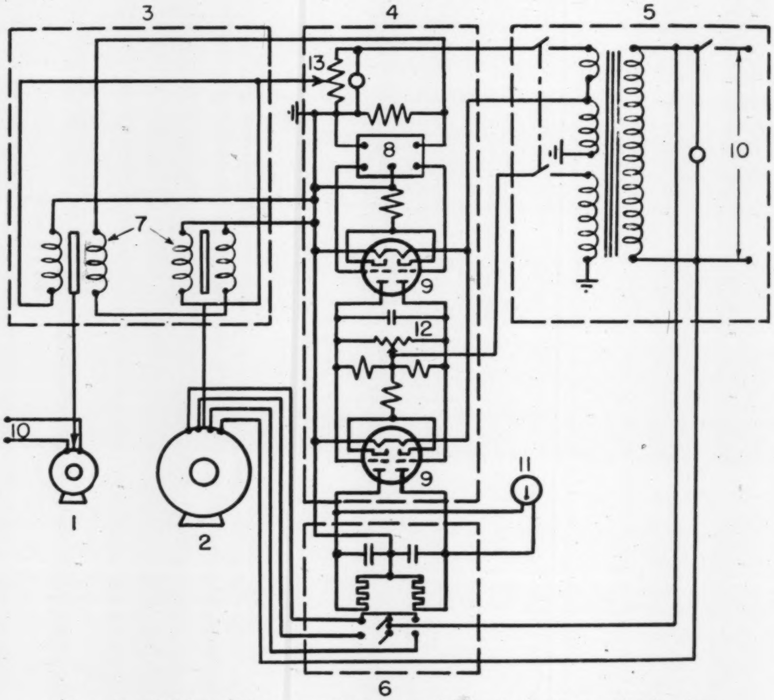


FIG. 8.—Wiring Diagram of Electro-Mechanical Servo Mechanism.

1. Input Motor (cam drive).
2. Output Motor (servo drive).
3. Transducer.
4. Amplifier.
5. Supply transformer.
6. Relay.
7. Differential transformers.
8. Input transformer.
9. 6 S N 7 G T.
10. 110 v., A-C. supply.
11. Balancing meter.
12. Balancing control.
13. Sensitivity control.

A block diagram of one of the five control units is shown in Fig. 7. Five pairs of linear differential transformers *9* represent the transducer (9) of a repeater system for any type of continuous linear motion. Three pairs of matched transformers control the eccentricity shifts and two similar pairs the phase shifts of the oscillator. One transformer of each pair, the sender, is on the control stand, *a*, the other, the repeater transformer, is fixed on the oscillator, *b*. The secondaries of each transformer pair are connected electrically in such a manner that an error voltage *10* is produced as soon as the positions of their cores with respect to their fields do not coincide. This error voltage is proportional to the relative change in transformer core position. On the control stand the position of each core is governed by five rotatable and interchangeable cams, *4*, driven by one input motor, *3*, at the required speed. Form and rotational speed of these cams correspond to the required rate of change in eccentricity and in phase of the three-mass systems. On the oscillator each core is connected by a rack and pinion drive to the five output shafts, *2*, governing eccentricity and phase. These shafts are driven by individual servomotors, *6*, via a worm gear reduction, *7*, which acts simultaneously as damping unit.

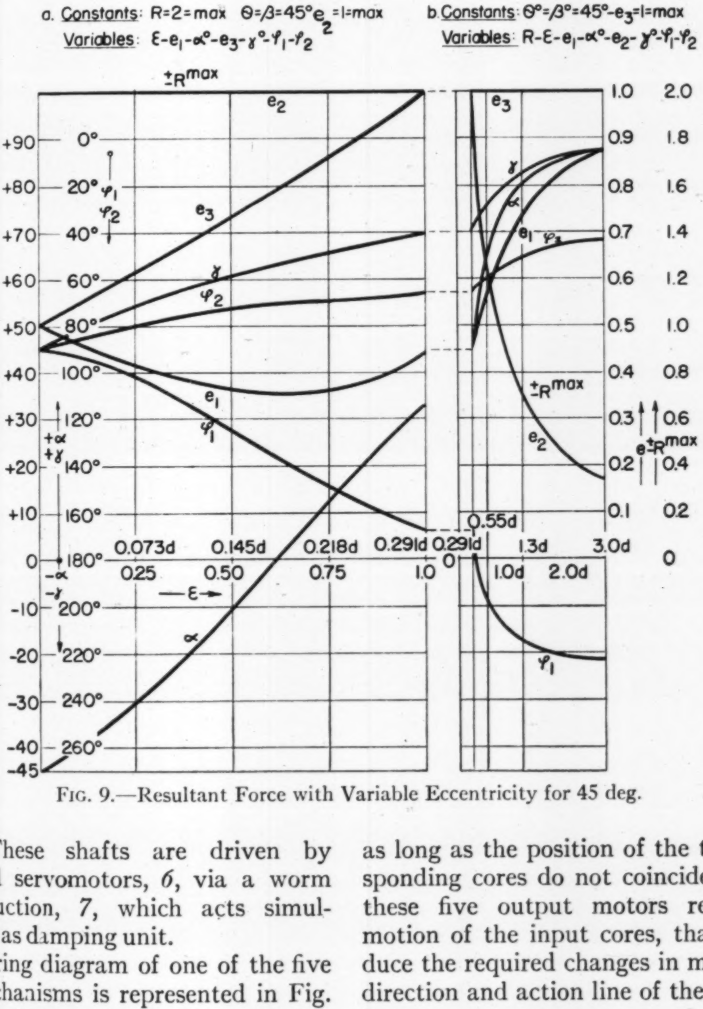


FIG. 9.—Resultant Force with Variable Eccentricity for 45 deg.

The wiring diagram of one of the five servo-mechanisms is represented in Fig. 8. For each transducer, *3*, a core displacement of ± 0.001 in. produces an output of approximately ±8 mv. The primaries of each pair of transformers are connected in parallel, the secondaries in series. The error voltage of each pair of transformers is amplified by two 6SN7GT tubes, *9*, connected as a two-stage push-pull amplifier, *4*, and fed into a sensitive, balanced, double-pole, double-throw relay, *6*. Each relay energizes one of the five servomotors, *2*, which rotate either forward or backward as long as the position of the two corresponding cores do not coincide. Hence these five output motors repeat the motion of the input cores, that is, produce the required changes in magnitude, direction and action line of the resultant force or moment vector. On Fig. 4, the remote control units, *5*, (five control cams and five corresponding differential input transformers) are visible. Also shown are the electronic units, *6*, with amplifier, balancing and sensivity control.

ANALYSIS

From a general point of view, the requirements for all controls may be subdivided into two types, *static* and *dynamic*.

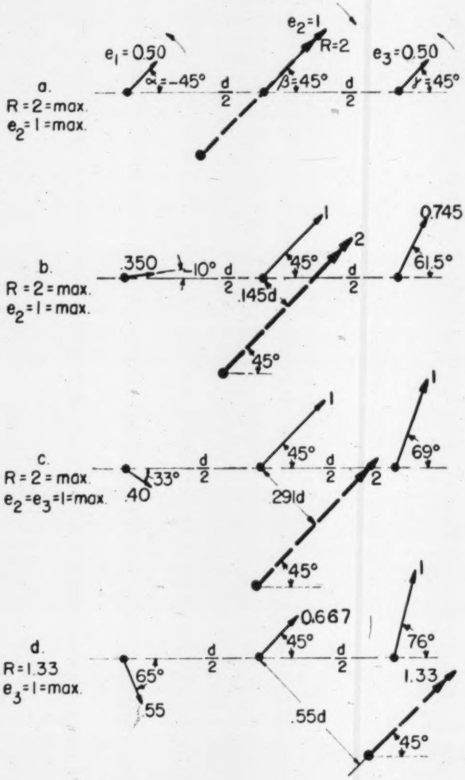


FIG. 10.—Resultant Force with Variable Eccentricity for 45 deg. Vector Diagrams.

For *static* controls it is assumed that the oscillator itself is not vibrating, that is, supported rigidly. For *dynamic* control the motion of the complete vibrating system, including the supports, has to be considered.

The *static* control is governed by the frequency, magnitude, direction and action line of the centrifugal force vectors. For constant unbalance the magnitude of the force vector increases with the square of the rotational speed of the eccentrically supported masses. This quadratic increase is an inherent characteristic of all mechanical oscillators with constant unbalance.

The *dynamic* control requires special means to compensate for inertia, and damping effects (phase angle). The compensation of these effects is of particular importance when working in or near resonance of the vibrating system, that is, the ascending or descending branch of the resonance curve.

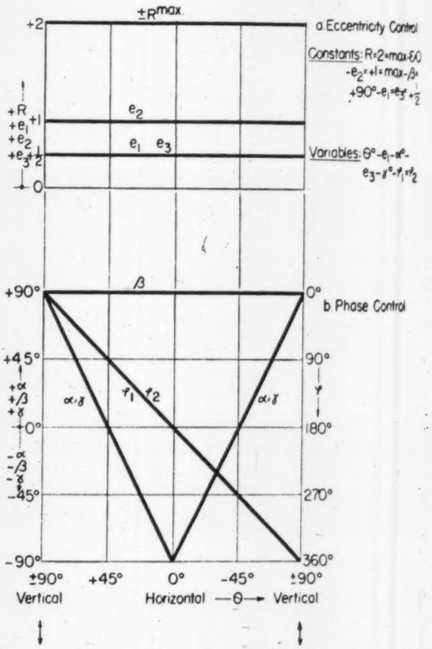


FIG. 11.—Resultant Force Rotating through Center of Oscillator.

In order to produce constant force- or moment vectors, regardless of the frequency, the three unbalances u_1, u_2, and u_3, must decrease with the square of the frequency. This may be achieved by substituting the input motor (*3* in Fig. 7) of the control unit by a speed responsive device. This device has to be connected to the eccentricity-control in such a form that the vectors e_1, e_2, and

e_3 decrease with the square of the frequency. Any centrifugal-force governor (Watt or Porter type) can be used for this purpose, since the vertical distance between the two rotating weights and their suspension point changes in inverse proportion with the square of the augular velocity of the weights.

Similar controls may be applied if constant displacement amplitudes, constant stress amplitudes, or constant frequencies are required. Instead of the speed responsive device, displacement-, stress-, or frequency-responsive instruments have to be inserted respectively. For constant displacement, or constant force vectors, strain gages can be attached directly to the test specimen or to an independent calibration member. The output of these strain gages controls the upper and lower envelope of the sinusoidal vibration within the frequency limits, including the resonance range. Photocell arrangements have been used effectively in similar cases (10). At resonant frequency of the vibrating system, excluding the specimen and neglecting damping, the inertia force becomes equal and opposite to the spring force. Hence both forces neutralize each other. For this particular frequency the maximum force in the specimen remains constant regardless of any variations in the elasticity of the specimen (11).

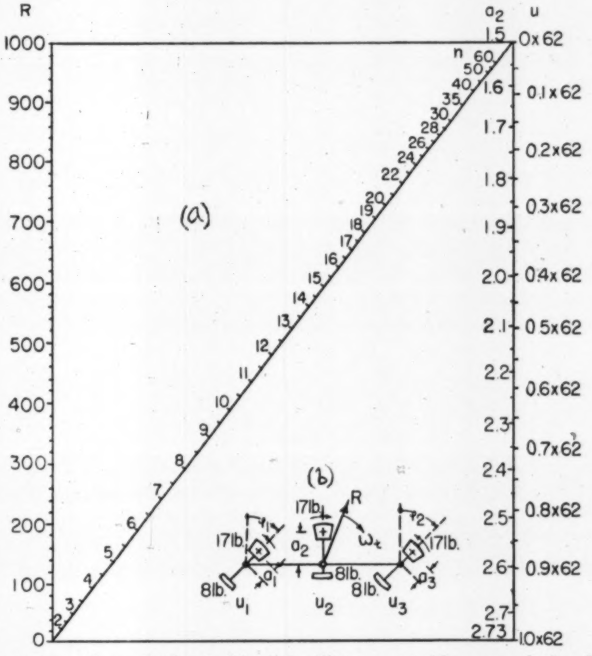


FIG. 12.—Resultant Force through Centroid of Oscillator. (*a*) Nomograph for One 17-lb. and One 8-lb. weight on Each Shaft. (*b*) Vector diagram of mass system.

$$R = (5.08\ a_2 - 7.62)\ n^2 \cos(\omega_t),$$

where:

R = resultant force vector in pounds,
a = distance between centroid of 17 lb. weights and center of rotation in inches,
n = number of revolutions of weights in cycles per second,
ω_t = time angle,
$\varphi_1 - \varphi_2$ = phase angles,
$u \times 62$ = unbalance in inch-pound, and
$u_1 = u_3 = \frac{1}{2} u_2$.

The static calibration diagrams (Figs. 9 to 17) represent a few characteristic examples of possible force vectors which can be induced with the oscillator when the center mass rotates in opposite direction to the two side masses. In order to make them of general application, dimensionless units are introduced. All letter symbols refer to the generalized vector diagram as shown in Fig. 3.

Three assumptions are made: First, the weights of the three masses, m_1, m_2, and m_3, are equal; second, the maximum eccentricities, e_1, e_2, and e_3, are equal to unity; and third, the vibrating system, including oscillator and excited mass have to be rigid enough to transmit forces and moments. These assumptions lead to the additional simplification that the unbalances, u_1, u_2, and u_3, and the three masses, m_1, m_2, and m_3, drop out and only the three eccentricity vectors, $e_1-\alpha$, $e_2-\beta$, $e_3-\gamma$, remain as dimensionless variables.

One Dimensional (Linear) Force Vector

The resultant static force vector, R, may have the following characteristics.

1. *Constant Direction of R. The Magnitude, R, and Eccentricity, ϵ, are the Only Variables:*

Figures 9 and 10 indicate these conditions for a 45-deg. force vector ($\beta = \theta =$ 45-deg. = constant).

The curves in Figs. 9 (*a*) and (*b*) show the variations of the eccentricity vectors in magnitude, e_1, e_2, and e_3, and direction, α and γ, the corresponding phase angles, φ_1 and φ_2, and the variation of the magnitude of the resultant force vector, R, plotted against the eccentricity, ϵ.

The vector diagrams in Figs. 10 (*a*) to (*d*) represent the action lines of the resultant, R, for four different eccentricities, ϵ.

For eccentricities larger than $\epsilon = 0.291d$, the resultant force vector has to be reduced; however, the eccentricity e_3 can be kept constant-unity.

2. *Constant Magnitude and Eccentricity of R. The Direction, θ, is the Only Variable:*

(*a*) *The resultant force vector, R, rotates through mass center of oscillator:*

Figures 11 and 12 indicate this condition for zero eccentricity of the resultant force vector, R.

For any linear motion between 0 and 360 deg., the required setting of the three eccentricity vectors, e_1, e_2, and e_3, in magnitude and direction and the phase angles, φ_1 and φ_2, is shown in Figs. 11(*a*) and (*b*).

The nomogram in Fig. 12 facilitates the determination of the magnitude of the resultant force vector, R (from 0 to 1000 lb), of the total unbalance u (from 0 to 62 in-lb.), or of the rotational speed, n (from 2 to 60 cycles per second), if two of the three values. R, u or n are given. In this particular case, each of the three rotating mass systems consists of one 17-lb. and one 8-lb. weight on opposite sides of their respective shafts, as shown in Fig. 12(*b*); the center unbalance, u_2, must be twice as large as each of the side unbalances, u_1 and u_3.

The equation represented in the nomogram is.

$$R = (5.08\, a_2 - 7.62)n^2 \cos \omega_t$$

where:

R = resultant force vector in pounds,

a = distance between centroid of 17-lb. weight and center of rotation in in.,

n = number of revolutions of weights in cycles per second,

$u \cdot 62$ = total unbalance in inch-pounds,

$u_1 = u_3 = 1/2\, u_2$, and

ω_t = time angle.

(*b*) *Resultant force vector R, not rotating through mass center of oscillator:*

This case is of particular importance for linear motions. In most practical applications the elastic center of the vibrating system does not coincide with the center of gravity (12) of the oscillator and the resultant force vector has to be adjusted accordingly.

The elastic center may be defined as a point through which the resultant force produces translatory motion only. Such a point exists in case of zero damping. line of the resultant force vector rotates through a fixed point on a vertical through the center of rotation of m_2.

The curves in Fig. 13 follow the variations of the three eccentricity vectors in magnitude, e_1, e_2, and e_3, direction,

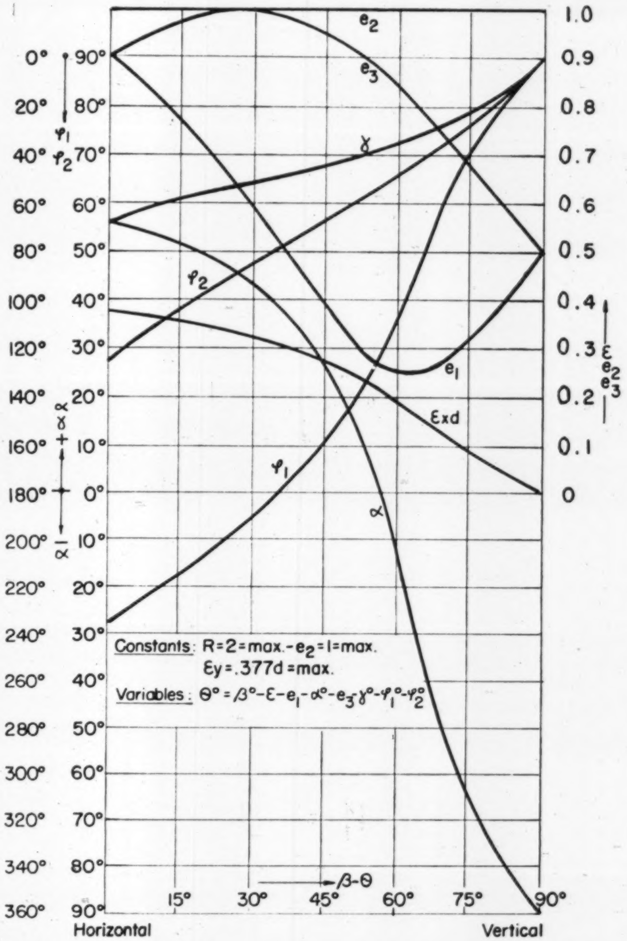


FIG. 13.—Resultant Force Rotating Through Point Below Center of Oscillator.

A detailed discussion of the elastic center, in particular for the case of damping, is beyond the scope of this report. Figures 13 and 14 represent conditions similar to those shown in Figs. 11 and 12. However, the action α, β, and γ, and their corresponding phase angles, φ_1 and φ_2, as well as the variations of the eccentricity, ϵ, of the resultant force vector for any linear motion between 0 and 90 deg. All curves are symmetric with respect to points on verticals for the angles $\theta = \beta = 0$ or π or 2π and so on. Hence the values for motions between 90 and 360 deg. can be determined accordingly.

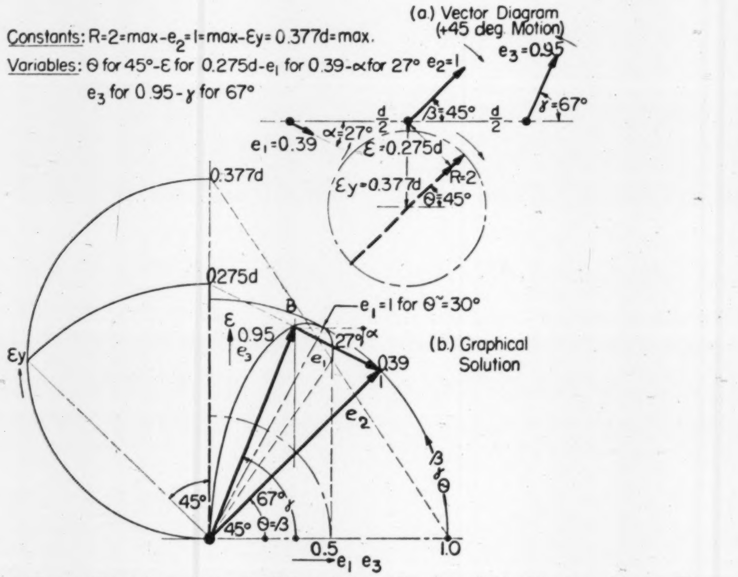

Constants: R=2=max-e2=1=max-Ɛy=0.377d=max.
Variables: Θ for 45°-Ɛ for 0.275d-e1 for 0.39-α for 27° e2=1
e3 for 0.95-γ for 67°
(a.) Vector Diagram (+45 deg. Motion)
e3=0.95
γ=67°
β=45°
d/2
d/2
e1=0.39
α=27°
Ɛ=0.275d
Ɛy=0.377d
R=2
Θ=45°
0.377d
0.275d
e1=1 for Θ≅30°
B
Ɛ
0.95
e3
27°
α
e1
.39
1
(b.) Graphical Solution
Ɛy
e2
β
γ
Θ
45°
67°
45°
Θ=β
0.5
1.0
e1 e3

FIG. 14.—Resultant Force Rotating through Point below Center of Oscillator. Vector Diagram and Graphical Solution.

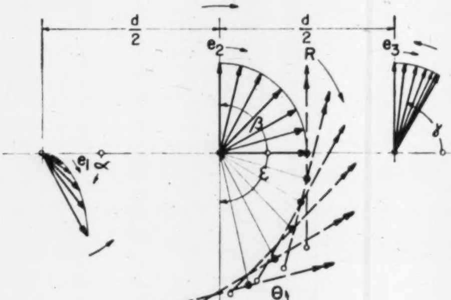

d/2
d/2
e2
R
e3
β
γ
e1
α
Ɛ
Θ
c
Constants: R=2=max-e2=e3=1=max.
Variables: Θ°=β°-Ɛ-e1-α-γ

FIG. 15.—Resultant Force Rotating with Maximum Eccentricity. Vector Diagrams.

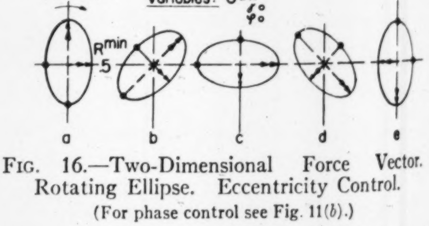

R^max
+1
+.75
+.50
+.125
0
e2
R^min
e1 e3
R
e1
e2
e3
Constants: R^max=1.00
R^min=.50
e2=.75-e1=e3=.125
β=+90°
Ɛ=0
Variables: Θ=α°
γ°
φ°
R^max=1
R^min
.5
a
b
c
d
e

FIG. 16.—Two-Dimensional Force Vector. Rotating Ellipse. Eccentricity Control. (For phase control see Fig. 11(*b*).)

The diagram in Fig. 14(*a*) represents the force vectors, *R*, for a 45-deg. direction and Fig. 14(*b*) the corresponding graphical solution. It should be kept in mind that the vertical distance between the point of rotation of *R* and the *Y*-axis, ϵ_y, must remain constant.

The elliptic curve in Fig. 14(*b*) indicates the location of all points of intersection between the two force vectors e_1 and e_3. For the angle $\theta = \beta \cong 30$ deg., the eccentricity vector e_3 becomes a maximum, that is, equals unity.

3. *Constant Magnitude of R. The Eccentricity, ϵ, and the Direction, θ, are the Only Variables:*

This condition is shown in Fig. 15. Keeping in mind that the force vector has to remain constant as well as a maximum, the eccentricity ϵ increases from 0.250 d (for a vertical force vector) to 0.437 d (for a horizontal force vector).

TWO-DIMENSIONAL (ELLIPTIC) FORCE VECTOR

1. *Stationary Elliptic Force Vector:*

Figure 16 indicates this condition: *a* and *e*, for an ellipse with the major axis vertical; and *c*, for an ellipse with the minor axis vertical.

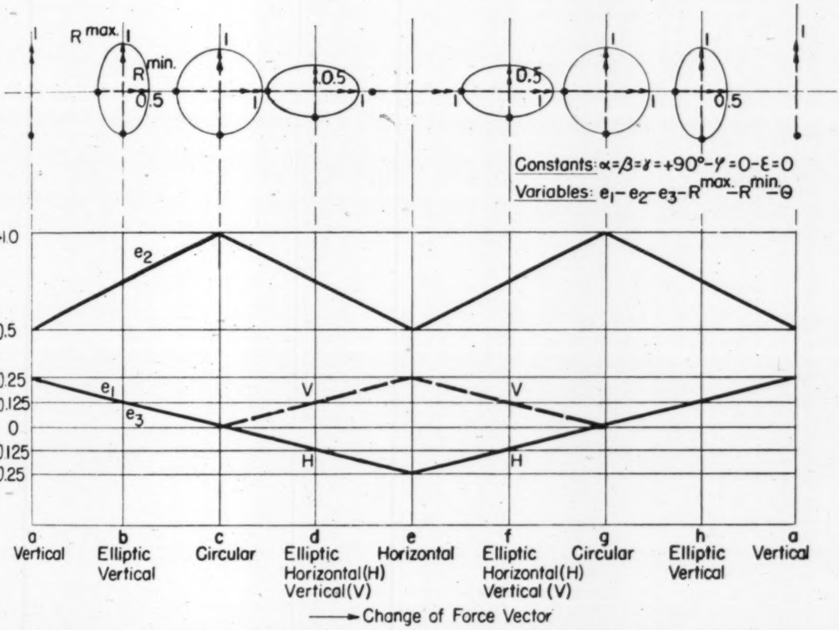

R max.
R min.
0.5
1
Constants: α=β=γ=+90°–γ=0–ε=0
Variables: e1–e2–e3–R max.–R min.–θ
+1.0
+0.5
e2
e1
e3
+0.25
+0.125
0
-0.125
-0.25
V
H
a Vertical
b Elliptic Vertical
c Circular
d Elliptic Horizontal(H) Vertical(V)
e Horizontal
f Elliptic Horizontal(H) Vertical (V)
g Circular
h Elliptic Vertical
a Vertical
Change of Force Vector

FIG. 17.—Change from One-Dimensional Force Vector into Two-Dimensional Force Vector. Degeneration of Circular Force Vector Into Straight-Line Force Vector.

A ratio of 2:1 is chosen for the maximum to the minimum diameter of the elliptic force vector. No change in phase angles, φ_1 and φ_2, is required since the magnitudes of the eccentricity vectors, e_1, e_2, and e_3, only have to be adjusted.

2. *Rotating Elliptic Force Vector:*

Figure 16 *a* to *e* indicates this force vector for one complete cycle. The phase control remains the same as shown in Fig. 11(*b*). However, compared with the linear force vector as represented in Fig. 11(*a*), the resultant force vector, R, and the three eccentricity vectors, e_1, e_2, and e_3, have to be reduced in magnitude.

3. *Periodic Degeneration of Circular Force Vectors into Straight Line Force Vectors:*

Changes of R from a vertical straight line via a vertical ellipse, into a horizontal straight line via a horizontal ellipse, and *vice versa* are indicated in Fig. 17, representing these conditions for one complete cycle. Both phase angles, φ_1 and φ_2, remain constant and equal to zero.

4. *Other Possible Force Vectors:*

In order to determine all one-dimensional force vectors which can be excited by the resultant force vector, the four elements which govern the characteristics of the force vector, that is frequency, magnitude, direction and action line, have to be kept either constant or can be varied.

The number of possible combinations of n elements, taken r at a time, is equal to the binomial coefficient $\binom{n}{r}$. Hence, for $n = 4$ elements, taken from $r = 0$ to $r = 4$ at a time, yields:

$$\sum_{r=0}^{r=4} \binom{n}{r} = \binom{4}{0} + \binom{4}{1} + \binom{4}{2} + \binom{4}{3} + \binom{4}{4} = 16$$

Thus sixteen different cases are theoretically possible. However, only a few examples which are of practical significance have been discussed more in detail.

The complete oscillator unit becomes self propelling by adjusting the resultant force vector with respect to magnitude and direction in such a way that the vertical component is large enough to lift the oscillator unit a small amount from its support while the horizontal component exerts simultaneously a forward thrust.

It is understood that a considerable number of other combinations between one-, two-, and three-dimensional force vectors can be induced.

In order to produce sinusoidal moments, all three centrifugal force vectors may rotate in the same direction, for example with the center vector of zero magnitude and one side vector 180 deg. out of phase. These conditions, however, are similar to those described above.

Finally, for three-dimensional force vectors the complete oscillator has to rotate around a vertical axis, causing vibrations in space, a discussion of which lies beyond the scope of this paper.

VECTOR-RULE

A small vector-rule (mechanical calculator) has been built which simulates the graphical solution (Fig. 14(b)). The three eccentricity vectors, e_1, e_2, and e_3, are represented by movable arms, made of thin transparent lucite strips and equipped with suitable scales to determine the magnitude of e_1, e_2, and e_3. The angles α, β, γ, and θ are given by the direction of the three eccentricity vectors and can be read on the corresponding angular scales. To simplify these scales, the angles α, β, γ, and θ are read from the + X-axis. Finally, a simple string and pulley drive keeps the vertical through B always at the midpoint of e_2.

For all scales dimensionless units are chosen in order to be independent of the physical dimensions of the oscillator. The maximum magnitude of the three eccentricity vectors, e_1, e_2, and e_3, is assumed equal to unity and the scale of the eccentricity ϵ of the resultant force vector, R is expressed in fractions of the distance between the two outer shafts d, divided by the eccentricity, e_2.

The vector-rule covers all values in the first quadrant, that is from a horizontal motion ($\theta = 0$) to a vertical motion ($\theta = 90$ deg.). The vectors in the three remaining quadrants can be determined, keeping in mind that the corresponding values are symmetric with respect to points on the ordinates for the angles $\theta = 0$ deg., π, 2π, etc. This has been demonstrated in some of the previous diagrams.

All possible settings for the eccentricities, e_1, e_2, and e_3, and the angles α, β, γ to obtain the desired resultant force vector in magnitude, R, direction, θ, and actionline, ϵ, or *vice versa*, can be determined in a few seconds. With this rather simple device an accuracy of ± 1 per cent has been obtained.

CONCLUSIONS

In all cases such as described previously or in cases of similar character, the resultant centrifugal force vector, **R, remains constant, rotates, or changes** periodically in frequency, magnitude, direction, or action line.

The resultant force vector will be either one- or two-dimensional if the eccentricity and phase control units follow the derived curves for the eccentricity vectors: e_1, e_2, and e_3, and phase angles: φ_1 and φ_2. These curves are smooth, that is, without abrupt changes, hence can be reproduced by simply inserting the corresponding cams into the servo mechanism.

It has to be kept in mind however, that any variations of the resultant motion caused by resonance or coupling effects or due to changes in the dynamic characteristic of the vibrating system have to be considered, regardless of whether these effects are intentional or accidental. Variations in the elastic or damping constants of the vibrating system, for example due to the development of fatigue cracks in the cross-section of a specimen, may be the source of such changes.

APPLICATIONS

The fields of applications for oscillators have been discussed extensively in technical literature. In the present method the pure sinusoidal form of the resultant force vectors makes all experiments easily reproducible. Only a few special cases, which characterize the versatility of the above described oscillator and which are not possible with previous machines, are mentioned.

Drive for Vibration Tables (13):

The change of eccentricity, that is, action line, of the resultant force vector while the machine is operating, allows:

1. The excitation of linear motions of the vibration table platforms by producing a force vector which passes through the elastic center of the vibrating system. A coincidence between this elastic center and the center of gravity of the oscillator is an exception. Furthermore, any mass added to the table, such as instruments to be calibrated, samples to be shaken, or soils to be vibrated, will change the location of the center of gravity of the complete system, thus, requiring readjustment of the force vector.
2. The reverse of this procedure, the determination of the center of gravity of a mass placed on the vibration table. In case two linear force vectors cause linear motions, their action lines will intersect in the elastic center of the vibrating system, and the location of the center of gravity may be inferred.
3. The vibration of the table platform in any direction either linear or two-dimensional.
4. The rotation of a linear or elliptic motion of the table with a predetermined period.
5. The change from linear to elliptical, or circular motions, or both, in predetermined periods.

Soil, Highway, and Airfield Dynamics (14, 15, 16, 17):

The possibility of producing force vectors in any direction, in particular horizontal forces in the plane of contact between oscillator and pavement or sub-soil surface, will facilitate the study of certain types of standing or propagation waves in the pavement or the subsoil.

The effect of these waves, first with respect to settlement or consolidation of soils, and second, with respect to failures caused by traffic vibrations in highway or airfield pavements, are of special interest. Furthermore, periodic impacts in one or more planes simultaneously might be excited in order to produce compaction effects in soils, particularly in soils with cohesive characteristics.

Finally, in connection with soil stabilization, it might be mentioned that the previously mentioned self-propelling characteristic of the complete oscillator unit is of considerable advantage.

Structural Units and Endurance Testing Machines (18 to 29):

The induction of pure linear vibrations in structures, component parts, or endurance-testing machines is sometimes rather difficult due to eccentricities not often avoidable. These undesirable eccentricities may be caused, for example, by clamping devices. They can be neutralized by selecting the resultant force vector of the mechanical oscillator in such a form that its action line passes through the elastic center of the vibrating system or of the specimen to be tested.

SUMMARY

The induction of periodic vibrations by means of mechanical oscillators has been advanced to such a stage that it may be considered as a fairly well established method. This holds true in particular when a sinusoidal characteristic of the exciter waves, easy reproducibility, or both, are essential.

The development of this method, however, seems by no means finished, and the author ventures the opinion that more fields of applications will be found in the future.

Acknowledgment:

The development of the mechanical three-mass oscillator is part of a research project supported by the Research Council and the Engineering Experiment Station of Rutgers University.

All experiments were made in the Dynamic Testing Laboratories at the Engineering Experiment Station of Rutgers University.

The oscillator was built by the Morehouse Machine Company; the main motor, including its control units, by Crocker-Wheeler Division of Joshua Hendy Corp.; and the differential transformers by the Schaevitz Engineering Co.

The technical advice of staff members of the College of Engineering, Rutgers University, in particular of Professor J. J. Slade, Director of the Engineering Experiment Station, who contributed to the theoretical development, and of Professors P. S. Creager and L. Rosenthal, who assisted in the design of the electrical controls, is greatly appreciated.

Messrs. B. Barshay and J. Finelli, Research Associates at the Engineering Experiment Station; Mr. K. Balkunow, Machinist; and Messrs. W. Pferd and H. Decker, former students, all at Rutgers University, helped the author during various steps of this development.

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DISCUSSION

MR. B. J. LAZAN.[1]—What is the order of magnitude of damping capacity encountered in soils? To state it differently, what range of resonance amplification factor can be expected with soils used as a spring element? The purpose of this question is to help clarify the justification for using resonant vibrations and the gain resulting from resonant operation in compaction and other soils vibration problems.

MR. G. P. TSCHEBOTARIOFF.[2]—Mr. Bernhard is to be complimented on this very interesting new development about which I have the following question. He referred to the vibration table which he had designed for us at Princeton several years ago. When we were discussing the general design of the table, the question came up, whether a two-mass mechanical oscillator could continuously operate for periods ranging between one and two weeks. This was our specific requirement because we wanted to run soil consolidation tests on the table. At that time, Mr. Bernhard was not certain whether even with a two-mass oscillator there wouldn't be breakdowns; so that he chose for the design of that table an electromagnetic oscillator described in his and Mr. Barry's paper in the ASTM BULLETIN.

He mentioned now that the new vibrating table at Rutgers uses this new three-mass oscillator. I am wondering whether Mr. Bernhard has overcome that difficulty in his design—I mean was the new oscillator so ruggedly built that it can operate continuously, or does the Rutgers' vibration table not require continuous operation?

I think that this specific point would probably be of considerable importance in the application of any such three-mass oscillators to soil compaction machines in the field; because although usually one does not employ compaction equipment continuously for several weeks on 24-hr. basis—still it can be expected to work at least 8 hr. a day or for longer periods. What does Mr. Bernhard think about this point?

MR. LAZAN.—We now have at Syracuse University seven oscillator-driven dynamic testing machines in continuous operation. Some tests made in these machines require continuous running times in excess of 10,000 hr. without stopping. Yet we have had no failures in bearings or oscillator parts. Fundamentally there is no reason why oscillator bearings should fail if properly designed, particularly in regard to outer race preload.

The Syracuse equipment utilizes single mass oscillators and requires no gears, whereas most portable type oscillators have at least two masses and require gears. However, multi-mass oscillators with gears can be designed for long service, as service records of many existing oscillators indicate.

Summarizing, I believe that most cases in which bearing or gear failures have occurred in oscillators were due to inadequate design rather than exceeding fundamental limitations.

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[1] Professor and Head, Dept. of Materials Engineering, Syracuse University, Syracuse, N. Y.

[2] Associate Professor of Civil Engineering, Princeton University, Princeton, N. J.

MR. A. W. JOHNSON.[3]—State Highway Departments are interested in different forms of vibratory compaction equipment. Many engineers have expressed the feeling that they are not getting adequate compaction of base courses and that they could well use some type of vibratory equipment, especially on the cleaner materials which are seemingly more in demand now than in the past.

Mr. Housel can tell, from their experiments, how vibratory compaction worked out in compacting granular materials.

MR. W. S. HOUSEL.[4]—We have been working for some time on a research in the consolidation of granular materials, but do not have any very extensive results to report at the present time. We are working with the commercially available vibrating plates and equipment. I can certainly check Mr. Walter Johnson on the fact that we, in the Soil Division, feel that the consolidation of base course materials is very much neglected and is possibly the place where we are missing out in getting the best jobs, particularly on rigid type pavements.

While our work is not advanced to the point where results can be reported, we have found out, for example, that some of the early plate vibrators did not have sufficient weight. The vibration, in itself, was not producing the results, and adding very substantial amounts of weight to these vibrating plates improved the results very materially.

It was found that the effective depth of such plate vibrators is probably 12 or 15 in. to produce as high a degree of densification in the granular materials as desired. However, measurable effects were produced down to the depth of about 36 in.

While we are talking about vibration, I might mention one interesting problem concerning vibration in granular materials that we have had recently, or as a matter of fact, have on our hands at this time. In the northern part of Michigan there is a diesel power plant built on about 90 ft. of sand which is in serious trouble due to vibration. Operation of the diesel plant causes vibrations that are felt about three blocks away. When the plant is operating it has been reported that the base of it settles at the rate of about an $\frac{1}{8}$ in. per 24 hr. We have been working on the problem of either eliminating the vibration or providing for continuous settlement. From the information that we have the vibration frequency of saturated sand is estimated at somewhere around 15 cycles per second, and the vibration frequency of this diesel unit is within 25 per cent of that.

So far this is just a problem, but the observations are evidence that vibrations under favorable conditions can be transmitted considerable distances through a soil mass and may produce a significant change in granular soils.

MR. R. K. BERNHARD (*author's closure*).—Referring to Mr. Tschebotarioff's comments, in general an electromagnetic drive permits higher frequencies but the magnitude of the induced force vector is limited when compared with a mechanical drive.[5] Furthermore the strong magnetic field of an electromagnetic drive might cause interference when the vibration table is used to calibrate sensitive electric instruments. Finally a mechanical three-mass oscillator drive permits a continuous change from one-, to two-, or even three-dimensional displacement without interruption of the test procedure, while with an electromagnetic drive such a continuous change would be rather difficult to obtain.

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[3] Engineer of Soils and Foundations, Highway Research Board, National Research Council, Washington, D. C.

[4] Associate Professor of Civil Engineering, University of Michigan, and Research Consultant, Michigan State Highway Department, Ann Arbor, Mich.

[5] See reference 13 of paper, p. 1032.

Mr. Lazan's statement that for long-time tests mechanical oscillators have been designed with adequate bearings and gear transmissions, the most important parts for long-time experiments, is very much to the point.

The experimental determination of soil damping, as referred to by Mr. Lazan, is by no means easy, mainly due to the nonlinearity of both the dynamic spring constant as well as damping constant of the soil. An attempt to overcome this difficulty will be started shortly.

As far as Mr. Johnson's request for dynamic soil compactors is concerned, one objective of the tests at Rutgers University is the development of such a machine. Dynamic soil compactors already on the market have been tested and the design of a general purpose soil compactor is on the drafting board.

Numerous tests at Rutgers University and by other investigators[6] have shown that certain natural frequencies for sands, including the exciter, are in the range of 20 cycles per second. Mr. Housel's experience that a frequency of 15 cycles per second of an exciter force on sand has caused serious troubles at large distances from this source of disturbance might be due to its closeness to the resonance range of the soil.

The author wishes to express his sincerest appreciation for the valuable contributions of the various discussers.

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[6] See references 4 and 14 of paper, p. 1032.

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON ACCELERATED DURABILITY TESTING OF BITUMINOUS MATERIALS

The Symposium on Accelerated Durability Testing of Bituminous Materials was sponsored by Committee D-4 on Road and Paving Materials and Committee D-8 on Bituminous Waterproofing and Roofing Materials and presented at the Seventeenth and Twentieth Sessions of the Fifty-second Annual Meeting of the American Society for Testing Materials held in Atlantic City, N. J., on June 30 and July 1, 1949.

This symposium consists of thirteen papers touching on such factors as the effect of ultraviolet light and water, mineral stabilizers, characteristics of carbon and light sources, the use of an abrasion test, immersion-compression comparison with traffic tests, and the design and application of a spark-gap instrument. In general all papers cover bituminous materials —asphalt, tar, and pitches—and their uses for both highway and roofing purposes. The papers presented are listed below:

A Review of Accelerated Test Methods for the Evaluation of Road Tars—E. O. Rhodes

Characteristics of Carbon-Arc Light Sources for Accelerated Exposure Testing—W. W. Lozier, M. R. Null, and F. T. Bowditch

Behavior of Bituminous Road Materials Under Accelerated Exposure Conditions and Laboratory Heat Tests—Richard H. Lewis

Accelerated Weathering of Road Tars—E. W. McGovern

Immersion-Compression Tests Compared with Laboratory Traffic Tests on Bituminous Concrete —A. T. Goldbeck

The Use of an Abrasion Test as a Measure of Durability of Bituminous Mixtures—John H. Swanberg and W. L. Hindermann

Test Methods for Performing Accelerated Durability Tests on Asphalts—T. E. Stanton and F. N. Hveem

Durability Tests—A Word of Caution—G. L. Oliensis

Accelerated Weathering of Pitches and Asphalts—W. F. Fair, Jr., H. R. Beck, and B. K. McKee

Mineral Stabilizers in Asphalt Roofings—L. Kirschbraun, R. H. Cubberley, and F. W. Yeager

A New Method for Evaluating Failure of Bituminous Materials Due to Weathering—J. B. Hunter, F. C. Gzemski, and L. Laskaris

The Design and Application of a Spark-Gap Instrument for Detecting Crack Failures of Asphalt Coatings During Weathering Tests—A. H. Boenau and L. A. H. Baum

Experience with Radiation in Accelerated Durability Tests on Bituminous Materials—Joseph Zapata

The papers together with discussions are issued as A.S.T.M. Special Technical Publication No. 94, entitled, "Symposium on Accelerated Durability Testing of Bituminous Materials."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON INDUSTRIAL GEAR LUBRICANTS

The Symposium on Industrial Gear Lubricants was held at a meeting of Technical Committee B on Lubricating Oils, of A.S.T.M. Committee D-2 on Petroleum Products and Lubricants, in Detroit, Mich., on June 22, 1948.

The information contained in the papers and discussions are to be used by the committee as a guide in determining which properties of industrial gear lubricants should be investigated for standardization of test methods, establishment of nomenclature and definitions, and preparation of specifications. The following three papers were presented:

Heavy Duty Gear Oils—E. M. Kipp, I. S. Kolarik, and C. A. Zeiler
Gear Lubricants Used in Steel Plants—John F. Pelly
Gear Set Servicing by the Cathode Ray Oscilloscope—A. R. Purdy and J. H. Goffe

The papers together with discussions are issued as A.S.T.M. Special Technical Publication No. 88, entitled, "Symposium on Industrial Gear Lubricants."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON LUBRICATION OF HIGH-SPEED TURBINE GEAR EQUIPMENT

The Symposium on Lubrication of High-Speed Turbine Gear Equipment was held at a Meeting of Technical Committee C on Turbine Oils, of A.S.T.M. Committee D-2 on Petroleum Products and Lubricants, in Washington, D. C., on February 14, 1949. The following papers were presented:

Introduction—F. C. Linn
Lubrication of Naval Gearing—R. T. Simpson
Developments in Gear Design and Their Lubrication Requirements—L. J. Collins
Physical Concepts of the Establishment of the Lubrication Oil Wedge and Its Associated Load Carrying Capacity for the Mating Tooth Surfaces of High-Speed Gears—Ernest K. Gatcombe
Fundamentals of Worm Gear Lubrication—A. R. Purdy

The papers together with discussion are issued as A.S.T.M. Special Technical Publication No. 92, entitled, "Symposium on Lubrication of High-Speed Turbine Gear Equipment."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON INSULATING OILS

This Symposium, the third of a series of Symposia on Insulating Oil, sponsored by Subcommittee IV on Liquid Insulation of A.S.T.M. Committee D-9 on Electrical Insulating Materials, was presented at a Meeting of Committee D-9 which was held in Washington, D. C., on March 23, 1949.

The two previous symposia were published in ASTM BULLETINS No. 146, May, 1947, pages 90 to 100 and No. 149, December, 1947, pages 58 to 94, and are also available in separate pamphlet form. The following papers were presented at the Washington, D. C., Meeting:

Introduction—E. A. Snyder and L. B. Schofield
Performance Characteristics of the Askarels—F. M. Clark
One System of Laboratory Testing to Appraise Serviceability of Oils in Transformers—R. G. Call
Performance of Inhibited Transformer Oils—G. H. von Fuchs

This third series of papers together with discussion are issued as A.S.T.M. Special Technical Publication No. 95, entitled, "Symposium on Insulating Oils."

EVALUATION OF MINERAL TRANSFORMER OIL DURING SERVICE[*]

PART I: THE CORRELATION OF OIL CHARACTERISTICS AFTER FORTY MONTHS OF SERVICE

By Frank M. Clark[1]

The proper selection of mineral transformer oil in order to avoid excessive oxidation and sludge formation during the use of the transformer has been the subject of numerous investigations. Subcommittee IV on liquid insulation, of A.S.T.M. Committee D-9 on Electrical Insulating Materials, has reported the results of its investigations.[2] Independent studies in the author's laboratory have also been presented.[3] From these researches, the Society has established Tentative Methods of Test for Sludge Formation in Mineral Transformer Oil (D 670 - 42 T).[4] Although these test procedures are believed to possess merit in establishing the relative sludging characteristics of new mineral oils, there still remains the problem of fixing quality specification limits for the acceptance of the oil in routine purchasing. Furthermore, an important problem which confronts all operators of mineral oil-filled transformers concerns the proper evaluation of the condition of the oil as it becomes progressively more oxidized in use. An operator must know the hazard, if any, which accompanies the continued use of the oil. Excessive sludging must be prevented. The establishment of the A.S.T.M. Tentative Methods D 670[4] procedures referred to presents a possible means for the solution of these two important and practical problems.

Heretofore it has been a common practice to evaluate the condition of mineral oil in transformer use from a study of its changing color and acidity. Maximum allowable acidity values have been variously set at 0.7 and 1.0 mg. of potassium hydroxide per gram of oil.

Concomitantly with the establishment of the sludge testing procedures, increasing consideration has been given the Tentative Method of Test for Interfacial Tension of Oil Against Water by the Ring Method (D 971 - 48 T)[5] for the evaluation of the oxidation condition of mineral oil in transformer use. It has been indicated that as the oil is continued in use, its interfacial tension value falls, ultimately reaching a value as low as 15 or 20. Interfacial tension values lower than about 20 are taken to indicate the need for oil replacement or reconditioning if excessive sludging is to be avoided.

In order to evaluate the various oil tests and to assist in the establishment of suitable specification limits for the proper selection of new mineral transformer oils, a cooperative testing program has been set up as one of the major activities of the A.S.T.M. subcommittee on liquid insulation. The results accumulated to date in the prosecution of this testing program are the subject of this paper.

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[*] Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] Technical Consultant on Insulation and Engineer of the Insulation Division of the General Engineering and Consulting Laboratory, General Electric Co., Schenectady, N. Y.

[2] F. M. Clark and E. A. Snyder, "Testing for Sludge Formation in Mineral Transformer Oil," *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part II, pp. 568–591 (1936).

[3] F. M. Clark, "Studies in the Oxidation of Mineral Transformer Oil," *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part II, pp. 507–519 (1938).

[4] 1946 Book of A.S.T.M. Standards, Part III-A, p. 946, or III-B, p. 628.

[5] 1948 Supplement to Book of A.S.T.M. Standards, Part III-A, p. 200.

The laboratories which are participating in these tests are:

Laboratory	*Representative*
American Gas & Electric Service Corp.	R. G. Call
Atlantic Refining Co.	K. G. Krech
Commonwealth Edison Co.	L. B. Schofield
Consolidated Edison of New York	C. T. Hatcher E. R. Thomas
De Laval Separator Co.	E. Banfield
Detroit Edison Co.	C. H. Fellows
General Electric Co.	F. M. Clark E. L. Raab
Gulf Research and Development Co.	C. E. Trautman
Hydro-Electric Power Commission	W. P. Dobson G. B. Tebo
Shell Oil Co., Inc.	H. H. Zuidema
Socony Vacuum Oil Co.	H. H. Dellinger W. G. Horsch C. A. Johnson E. A. Snyder
Standard Oil Co. of Calif.	C. H. Lynam
Standard Oil Co. of Ind.	C. M. Loane
Standard Oil Co. of N. J.	I. E. Manning
Sun Oil Co.	E. S. Ross W. C. Witham
Texas Co.	R. J. Harrington
Tide Water Associated Oil Co.	L. Mittelman
Westinghouse Electric Corp.	T. K. Sloat
West Penn Power Co.	O. E. Fawcett

GENERAL METHOD OF STUDY

In order to obtain a wide variety of operating conditions typical of American practice, 18 transformers as described in Table I are being used in the tests. Table II gives the properties of the oils used.

TABLE I.—DESCRIPTION OF TRANSFORMERS IN TEST.

Designation	Type	Quality of Oil Used	Location of Transformer
A-1	Open-breather	Good	Detroit Edison
A-2	Open-breather	Poor	Detroit Edison
A-3	Open-breather	Medium	Detroit Edison
K	Open-breather	Reclaimed	Detroit Edison
J	Open-breather	Good	American Gas
B-4	Nitrogen-seal	Good	Detroit Edison
B-5	Nitrogen-seal	Poor	Detroit Edison
B-6	Nitrogen-seal	Medium	Detroit Edison
D	Nitrogen-seal	Good	Commonwealth Edison
E	Nitrogen-seal	Good	Commonwealth Edison
F	Nitrogen-seal	Good	Commonwealth Edison
L	Nitrogen-seal	Reclaimed	Detroit Edison
C-7	Water-cooled	Good	Detroit Edison
C-9	Water-cooled	Medium	Detroit Edison
G	Water-cooled	Reclaimed	New England Power
H	Water-cooled	Reclaimed	New England Power
I	Water-cooled	Reclaimed	New England Power
M	Water-cooled	Reclaimed	Detroit Edison

METHOD OF TEST

Oil samples are removed from the transformers at intervals of about one year during normal operation. These samples are tested by the cooperating laboratories in accordance with the following procedures:

- Color
- Neutralization number
- Sludge value
  - by pressure oxidation, and
  - by accumulation
- Interfacial tension

TABLE II.—INITIAL CHARACTERISTICS OF THE TRANSFORMER OILS STUDIED.

Oil designation	New	New	Good	Medium	Poor	Reclaimed		
Transformers	J	D E F	A-1 B-4 C-7	A-3 B-6 C-9	A-2 B-5	M	K L	G H I
ASTM Sludge:								
3 days	0.038	0.051	0.047	0.094	0.398	0.086	0.125	0.085
7 days	0.108	0.156	0.126	0.29	1.19	0.274	0.520	0.300
14 days	0.181	0.403	0.232	0.64	2.98	0.548	1.294	0.850
Pressure-oxidation sludge	0.021	0.024	0.026	0.078	0.185	0.121	0.151	0.242
Neutralization value	0.008	0.014	0.016	0.039	0.76	0.115	0.129	0.045
Color	¾	¾	¾	1¼	4	2¼	2¼	2¾
Interfacial tension	48.2	51.3	41.7	33.3	26.4	27.6	29.5	30.7

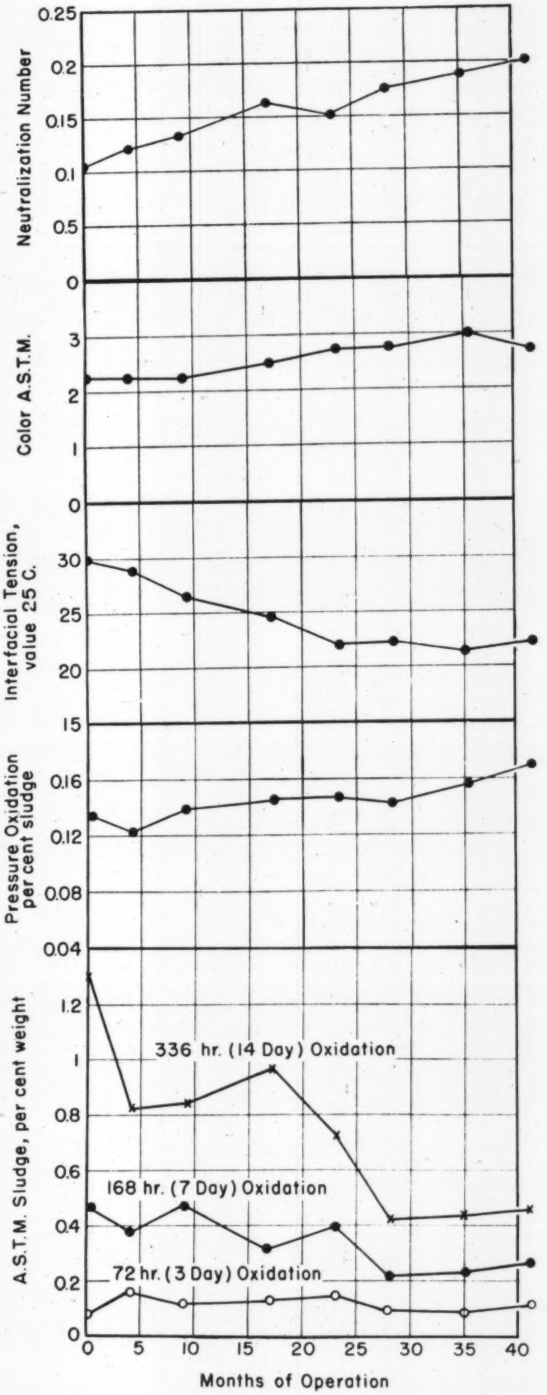

FIG. 1.—Neutralization Number, Color, Interfacial Tension, Pressure Oxidation, and Sludge Accumulation Values for Reclaimed Oil as Affected by Commercial Use in Transformer K.

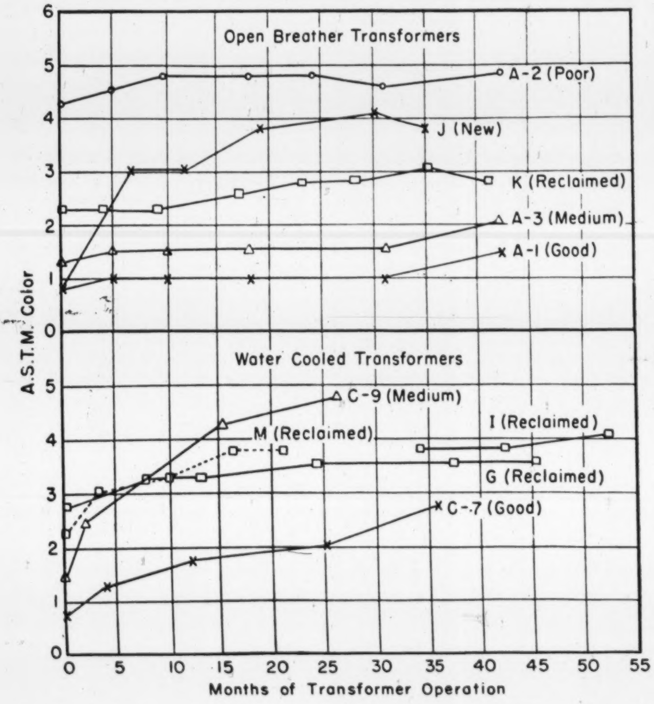

FIG. 2.—The Color Value for the Mineral Transformer Oils as Affected by Operation in Open-Breather and in Water-Cooled Transformers.

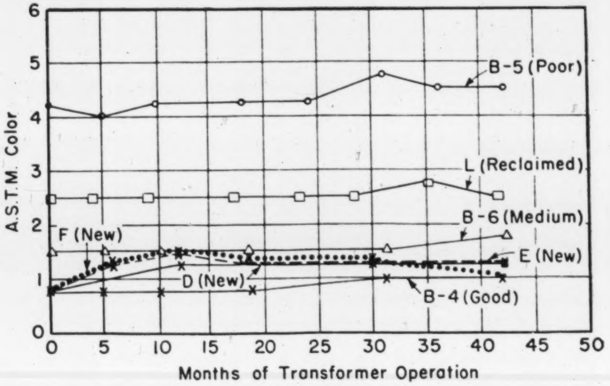

FIG. 3.—The Color Value for Mineral Transformer Oils as Affected by Operation in Nitrogen-Seal Transformers.

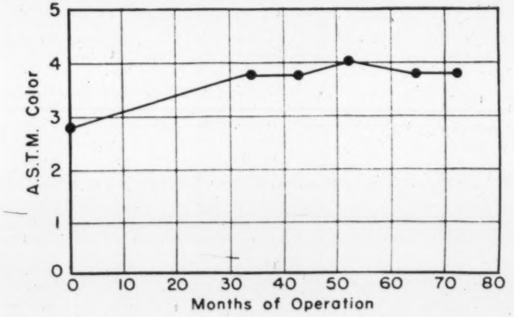

FIG. 4.—The Color of Reclaimed Mineral Transformer Oil as Affected by Operation in Water-Cooled Transformer I.

In addition, other test data are obtained at the option of the testing laboratory. Test data that are being accumulated but which are not included in the present summary are:

- Steam emulsion
- Resistivity
- Power factor
- Water content
- Dielectric strength

In the present summary, all data reported are average data based on the total results submitted by the cooperating laboratories. Future analyses will include a survey of the test variations and other pertinent factors for those tests which are found to be of practical utility to the purchaser and user of the oil.

Interpretation of Test Data:

In this summary, no effort is made to compare the stability of the mineral oils as a function of the design of the transformer in which they are used. In general, the varying factors of transformer age and operation make conclusions of this type highly speculative. Such a study will be reserved for later analysis when the test data are more extensive.

This report does, however, attempt to elucidate the changes observed in the various oil properties. The observations and conclusions drawn will be subject to review as further operational data are accumulated.

The Operator's Problem:

The operator of a transformer desires information concerning the degree of hazard entailed in the continued use of the oil in his transformer. It is only natural to believe that such information can be obtained from an examination of the oil itself and it is on this basis that most operators have proceeded in setting up of limitations for oil color, oil acidity, and the like as criteria of the maximum oxidation to be permitted in the oil. But if one expects to find that an oil which is increasing most rapidly in color, acidity, sludging propensity, and in other characteristics is one which presents the greatest hazard in use, then a review of the data present in Figs. 1 to 18 which summarize the average values of the tests reported by the cooperating laboratories will be most perplexing.

To grade oils on the basis of their oxidation stabilities in use is frequently difficult since a "flattening off" or even an improvement in one oil property value is sometimes observed while other oil characteristics are showing normal deterioration as the oxidation progresses. A typical example of this behavior is illustrated for the oil drawn from transformer K. Although the neutralization number, color, interfacial tension, and pressure oxidation characteristics of this oil are deteriorating in the expected manner, the sludge accumulation values are showing a steadily decreasing characteristic for the 7- and 14-day tests (Fig. 1). Other conflicting trends in oil properties will be observed in the data submitted. It is not realistic, therefore, to expect unanimity of opinion even in correlating test data for the limited number of transformers under consideration.

In the following tabulations are listed the transformers which have been showing the greatest oil deterioration rate during operation to date. The smaller the rating number, the greater the oil deterioration observed:

	Transformer Showing the Greatest Oil Change		
	Rating No. 1	Rating No. 2	Rating No. 3
Color	C-9	J	C-7
Neutralization number	C-9	M	C-7
14-day sludge	E	D	H
Pressure oxidation	G	A-2	B-5
Interfacial tension	A-2	M	I

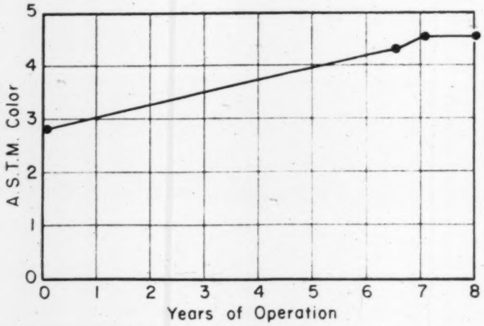

FIG. 5.—The Color of Reclaimed Mineral Transformer Oil as Affected by Operation in Water-Cooled Transformer H.

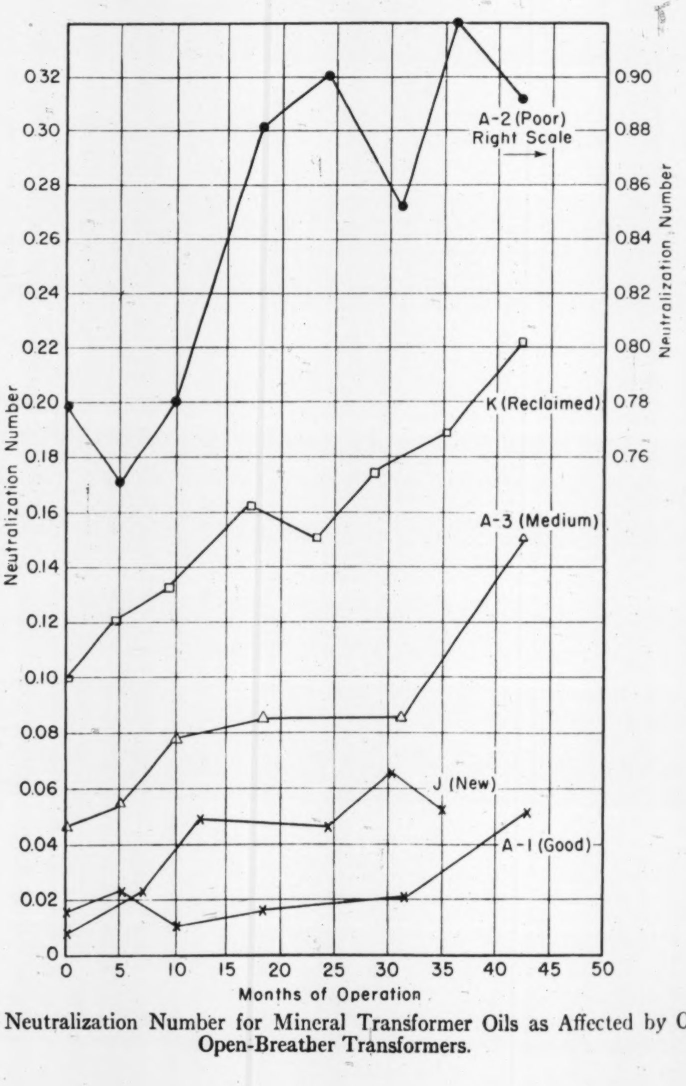

FIG. 6.—The Neutralization Number for Mineral Transformer Oils as Affected by Operation in Open-Breather Transformers.

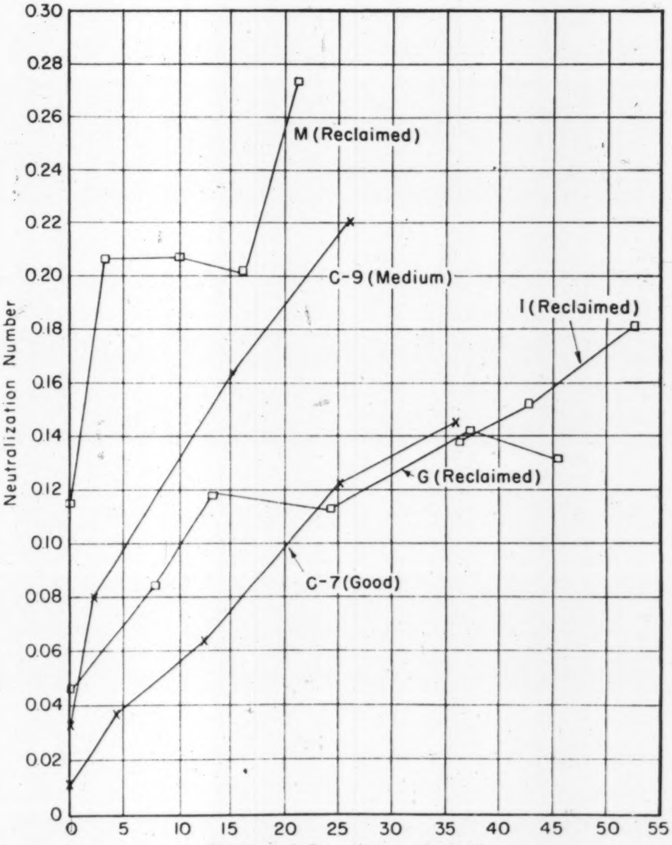

FIG. 7.—The Neutralization Number for Mineral Transformer Oils as Affected by Operation in Water-Cooled Transformers.

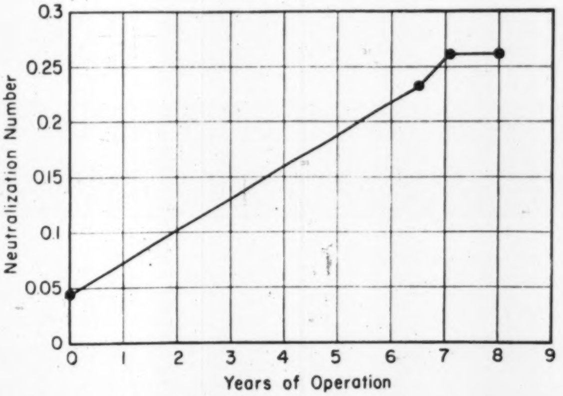

FIG. 8.—The Neutralization Number for Reclaimed Mineral Transformer Oil as Affected by Operation in Water-Cooled Transformer H.

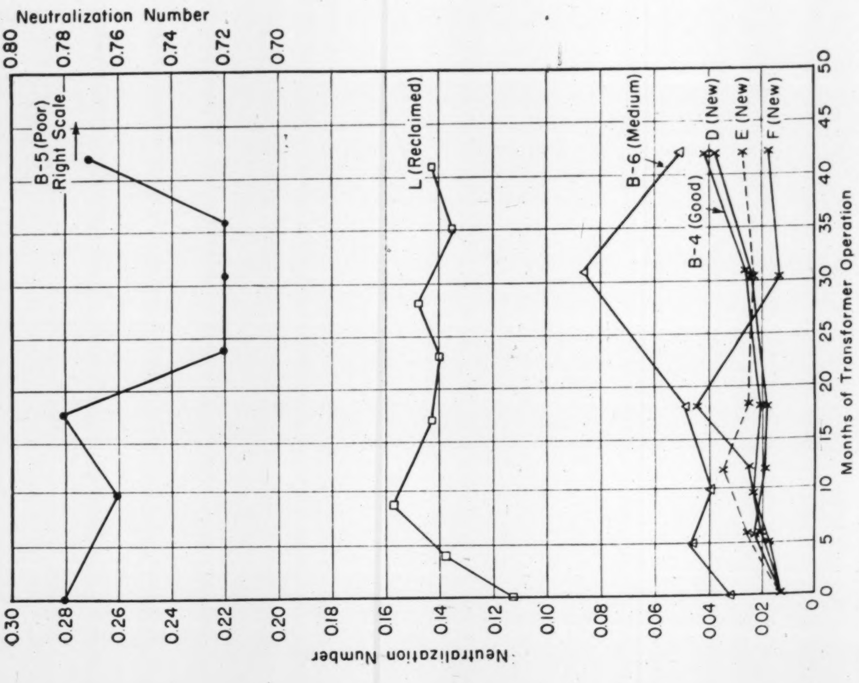

FIG. 9.—The Neutralization Number for Mineral Transformer Oils as Affected by Operation in Nitrogen-Seal Transformers.

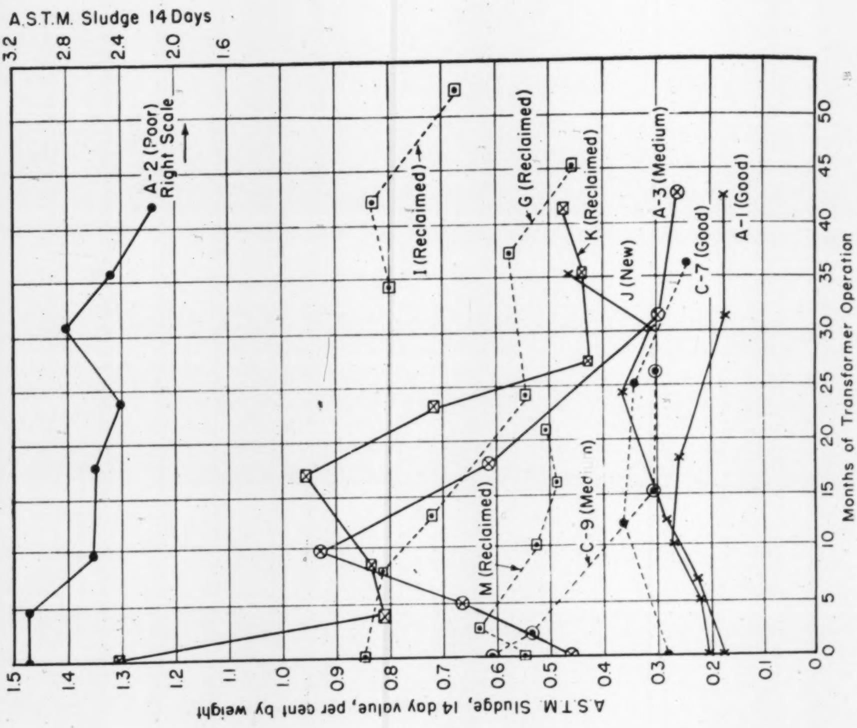

FIG. 10.—The 14-day Sludge Accumulation Value for Mineral Oils as Affected by Operation in Open-Breather and Water-Cooled Transformers.

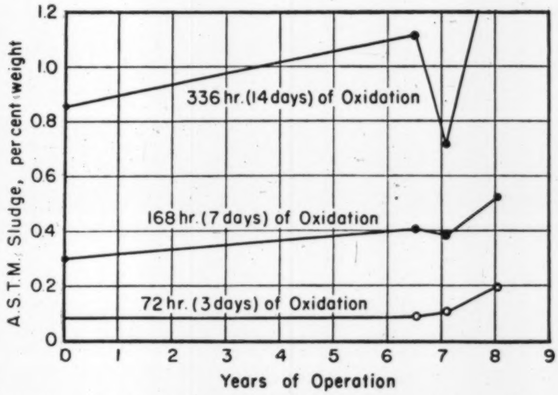

FIG. 11.—The Sludge Accumulation Value for Reclaimed Mineral Oil as Affected by Operation in Water-Cooled Transformer H.

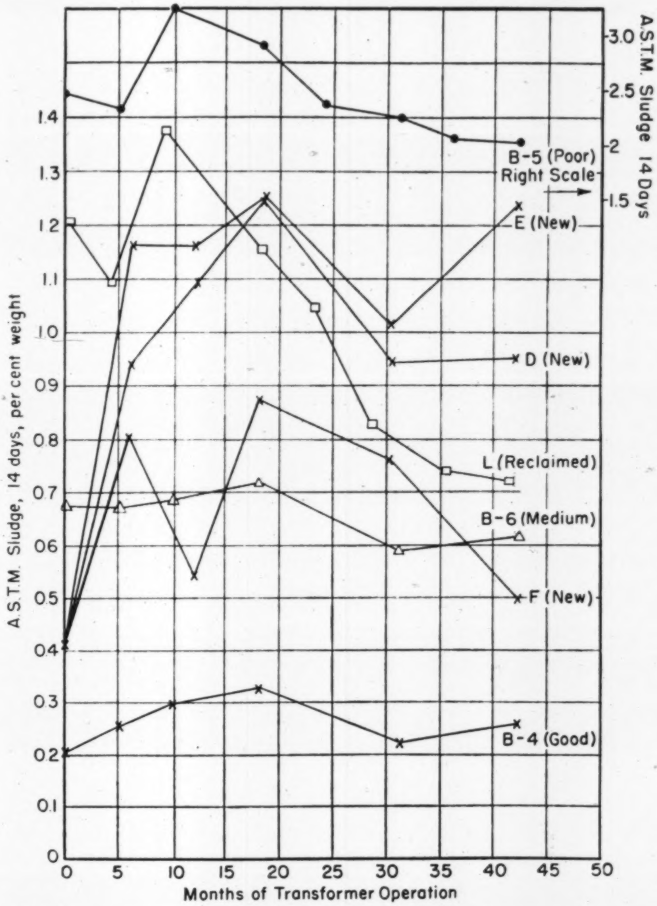

FIG. 12.—The 14-day Sludge Accumulation Value for Mineral Oils as Affected by Operation in Nitrogen Gas Cushion Transformers.

In the foregoing tabulation, the absolute value of the oil property is given but little weight, emphasis being placed on the rate of oil deterioration as indicated by the change in the property inspected. For example, oil in transformer A-2 has a high color but the change in color from the initial value has been negligible. On a color basis, the oil in transformer A-2 is considered to be more stable than the oil in transformer J which has shown a marked color increase during the transformer operation. As the test program progresses, it will be possible to apply the maximum permissible (limiting) oil-property values as is more customarily done in American transformer maintenance.

The lack of agreement in the "rating" of the transformer oils in the preceding tabulation is worthy of further analysis.

OBSERVATIONS BASED ON THE OIL TEST DATA REPORTED

Although final conclusions cannot be drawn until more extensive operating experience is secured, general observations concerning the trends and the relationships of the various oil properties which have been recorded up to this time will be of interest.

Oil Color:

The oil color values reported have been summarized in Figs. 2 to 5. In studying these data, it will be recalled that three grades of quality are represented by the oils used: a good quality considered suitable for transformer use, a poor quality not suitable for transformer use, and a medium quality which is generally believed to be suitable for transformer use but the use of which might well be questioned. In addition, some reclaimed oils are included.

It will be observed that:

1. In open-breather transformers (Fig. 2), the color stability appears unrelated to the expected quality rating of the oil (good, poor, or medium). A darker initial oil color is not reflected in oil (color) instability.
2. Rapid deterioration in oil color has taken place in transformer J, a reconditioned transformer, which will offer an opportunity for later test correlation.
3. The oils in the water-cooled transformers darken more rapidly than do the same oils in the open-breather transformers.
4. Oil color changes in the nitrogen-seal transformers are negligible.

Neutralization Number:

The neutralization values reported for the various oils are summarized in Figs. 6 to 9. It will be observed that:

1. All oils show increase in neutralization number during operation in open-breather transformers (Fig. 6). This contrasts with the color stability reported in Fig. 2.
2. In both the open-breather transformers (Fig. 6) and the water-cooled transformers (Fig. 7), the increase in the neutralization number of the oil is in almost linear relation to the duration of transformer operation, although wide differences in the rate of change are observed.
3. None of the oils have shown severe changes in the neutralization number during operation in the nitrogen-seal transformers (Fig. 9).
4. The neutralization number of the oils in the water-cooled transformers increases at a faster rate than do the corresponding oils in the open-breather transformers (Figs. 6 and 7). This agrees with the color changes already noted.

Sludge Accumulation:

The sludge accumulation data have given anomalous behavior. In many instances, a decrease in the sludge accumulation value has been observed during the operation of the transformer. This has been true especially with the 14-day accumulation results, but there are indications that the 3-day and the 7-day values will behave similarly as the transformer operation is continued. The 14-day accumulation test results are summarized in Figs. 10, 11, and 12. Because of the erratic nature of the test results, it is difficult to analyze their significance. It is of interest to observe, however, that:

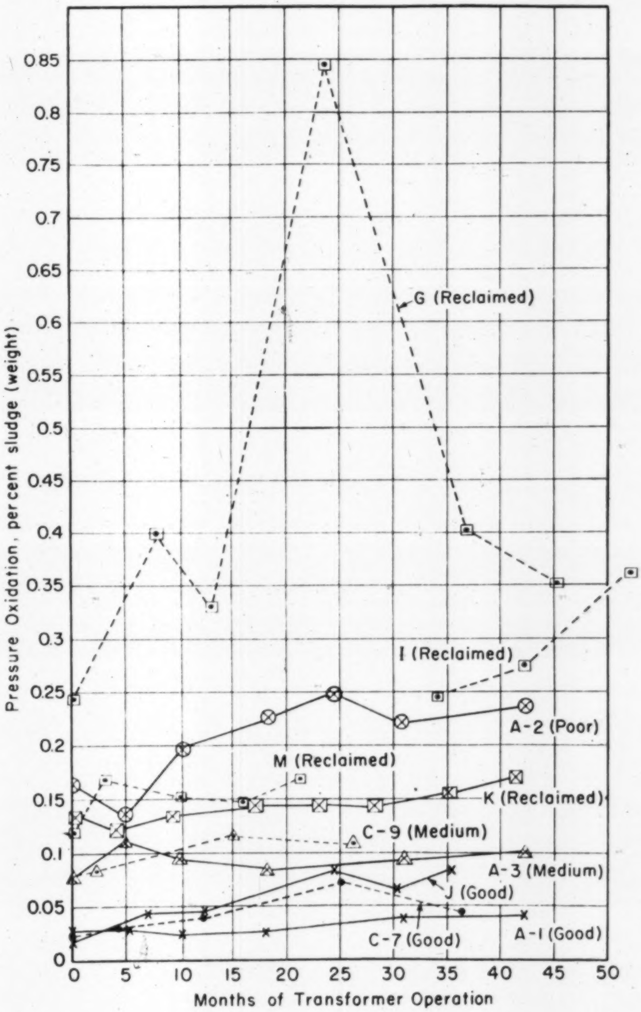

FIG. 13.—The Pressure Oxidation Sludge Value for Mineral Oils as Affected by Operation in Open-Breather and Water-Cooled Transformers

1. The two types of acceptable quality oils behave differently. "Good"

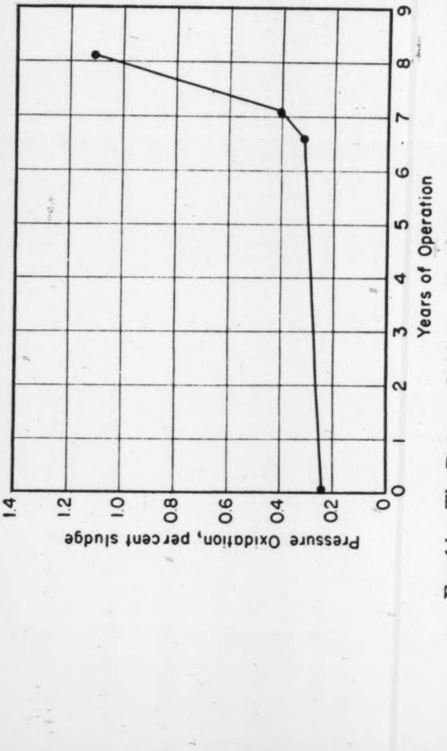

FIG. 14.—The Pressure Oxidation Sludge Value for Reclaimed Mineral Oil as Affected by Operation in Water-Cooled Transformer H.

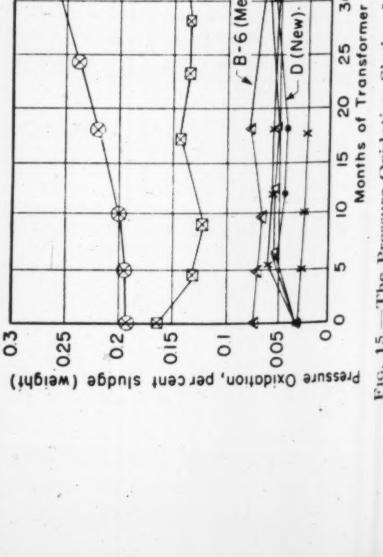

FIG. 15.—The Pressure Oxidation Sludge Value for Mineral Oil as Affected by Operation in Nitrogen-Seal Transformers.

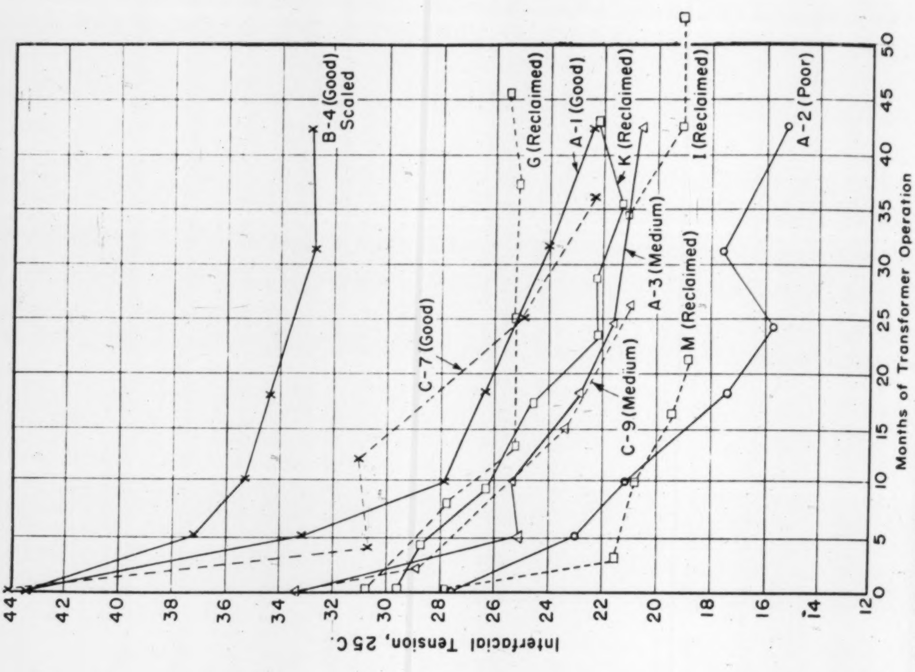

FIG. 16.—The Interfacial Tension Value for Mineral Oils as Affected by Operation in Open-Breather and Water-Cooled Transformers.

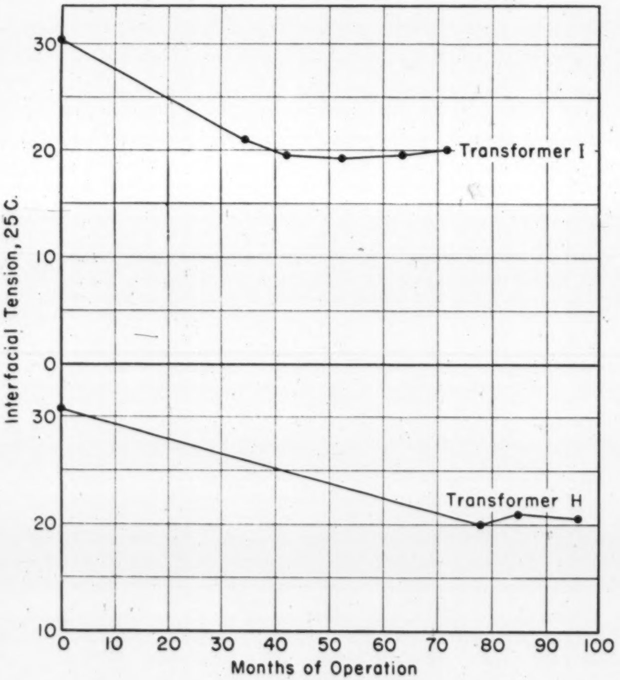

FIG. 17.—Interfacial Tension Values for Reclaimed Mineral Oil as Affected by Operation in Water-Cooled Transformers H and I.

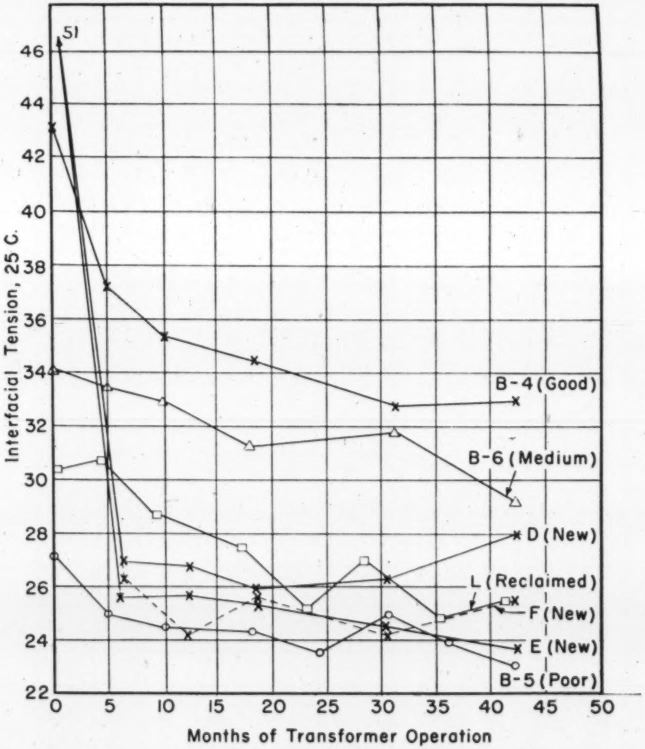

FIG. 18.—The Interfacial Tension Value for Mineral Oil as Affected by Operation in Nitrogen-Seal Transformers.

quality oil is stable in all three types of transformers tested (A-1, C-7, and B-4).

The acceptable quality oil designated as "new" shows an increasing sludge value in the open-breather (J) and the nitrogen-seal transformers (D, E and F). This oil was not tested in the water-cooled type of transformer.

This contrasting behavior of the two types of oil warrants further study.

2. The medium quality, the poor quality, and the reclaimed oils show stable or decreasing sludge values in all three types of transformers with the exception of reclaimed oil H.
3. A high initial sludge accumulation value is not a criterion of rapid deterioration in the sludge accumulation characteristic during transformer operation.

The value of the sludge accumulation characteristic of an oil as a gage of oil (oxidation) condition during transformer use is doubtful in the light of normal service experience. However, final conclusion must be postponed until the examination of the transformer windings is made.

Pressure (Sludge) Values:

The pressure oxidation (sludge) values show none of the erratic features of the sludge accumulation test, with the exception of a single test point in the data for the reclaimed oil in the water-cooled transformer H (Fig. 14). In general, as expected on the basis of experience, a stable or slowly rising sludge value is observed in the pressure oxidation characteristic of the various oils. The data are illustrated in Figs. 13, 14, and 15. From these data it will be observed that:

1. The oils designated as "good" and "new," which on the basis of experience should be of acceptable quality, are showing little, if any, deterioration to date in any of the three types of transformers. The medium quality oil is also showing a stable characteristic.
2. The reclaimed oils in open-breather transformer K and in nitrogen-seal transformer L (Figs. 13 and 15) are stable. In the water-cooled transformers G, H, and I, the reclaimed oil is showing an increased pressure oxidation sludge value (Figs. 13 and 14).
3. The "poor" grade oil in the open-breather transformer A-2 (Fig. 13) and nitrogen-seal transformer B-5 is showing deterioration.

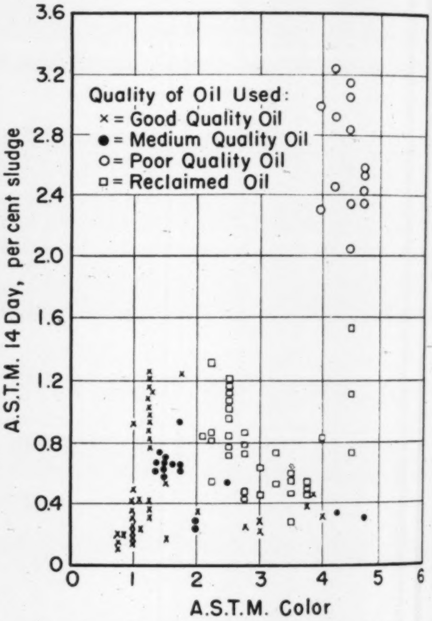

FIG. 19.—Showing the Lack of Correlation in the Change in Color and 14-day Sludge Accumulation Sludge Values which have been Produced in Mineral Oil as the Result of Commercial Transformer Operation.

Interfacial Tension Value:

In general, the analysis of the interfacial tension test data leads to observa-

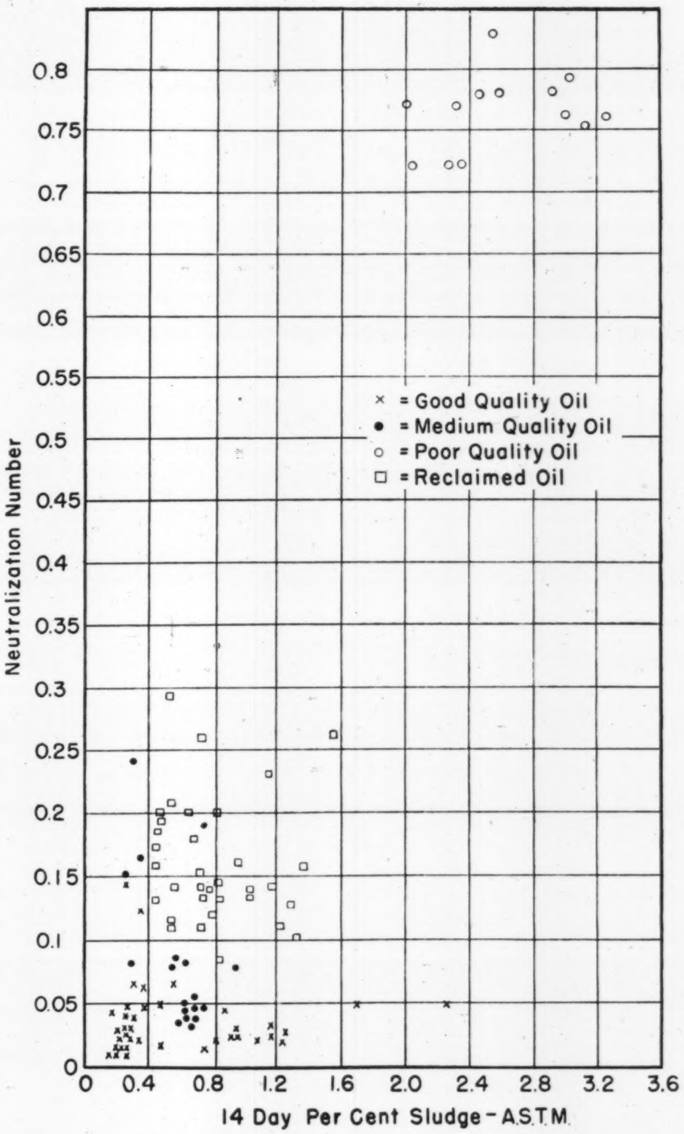

FIG. 20.—Showing the Lack of Correlation in the Change in Neutralization and the 14-day Sludge Accumulation Values which have been Produced as the Result of Commercial Transformer Operation.

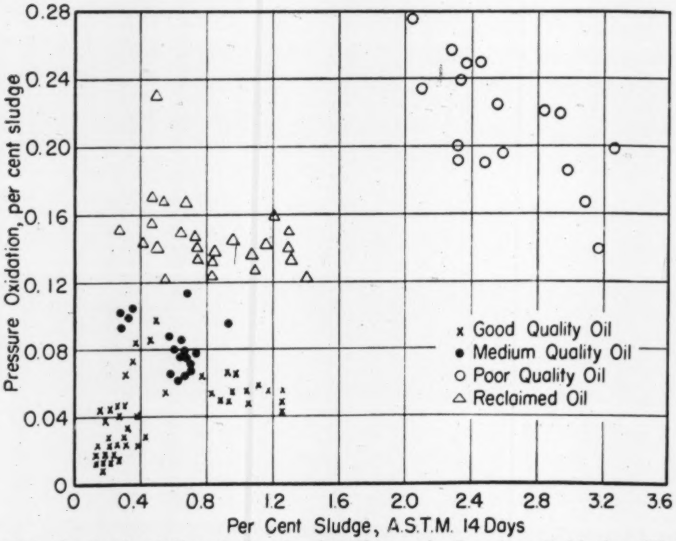

FIG. 21.—Showing the Lack of Correlation in the Change in Pressure Oxidation (Sludge) and the 14-day Sludge Accumulation Values which have been Produced in Mineral Oil as the Result of Commercial Transformer Operation.

tions which are consistent with performance expectations based on experience and provides a basis for further experimental studies. The results obtained to date are illustrated in Figs. 16, 17, and 18. It will be observed from the data that:

1. The good, new, medium, and poor oils are deteriorating in the expected order in the various types of transformers tested. Comparison data relating the period of operation necessary to reduce the interfacial tension value to 22 are summarized as follows:

Oil Used	Type of Transformer	
	Open Breather	Water-Cooled
Good quality	45 months	21½ months
Medium quality	36 months	20 months
Poor quality	7½ months	...

2. The oils in the nitrogen-seal transformers are showing greater stability, and none have reached the 22 interfacial tension value. The quality performance comparison can be indicated by a listing of the interfacial tension values after 42 months of operation (Fig. 18):

Good oil (B 4)	32.8
Medium oil (B 6)	29.0
New oil (D)	27.9
New oil (F)	25.4
New oil (E)	23.6
Poor oil (B-5)	22.9

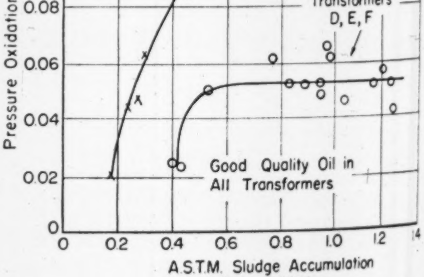

FIG. 22.—Showing the Contrasting Relationships which have been Established Between Pressure Oxidation Sludge Value and the 14-day Sludge Accumulation Characteristic for Good Quality Oils During Commercial Transformer Operation.

3. The reclaimed oils are showing the expected interfacial tension characteristic.

other oil properties. This is illustrated in Figs. 19, 20, and 21 in which the attempt is made to correlate the 14-day

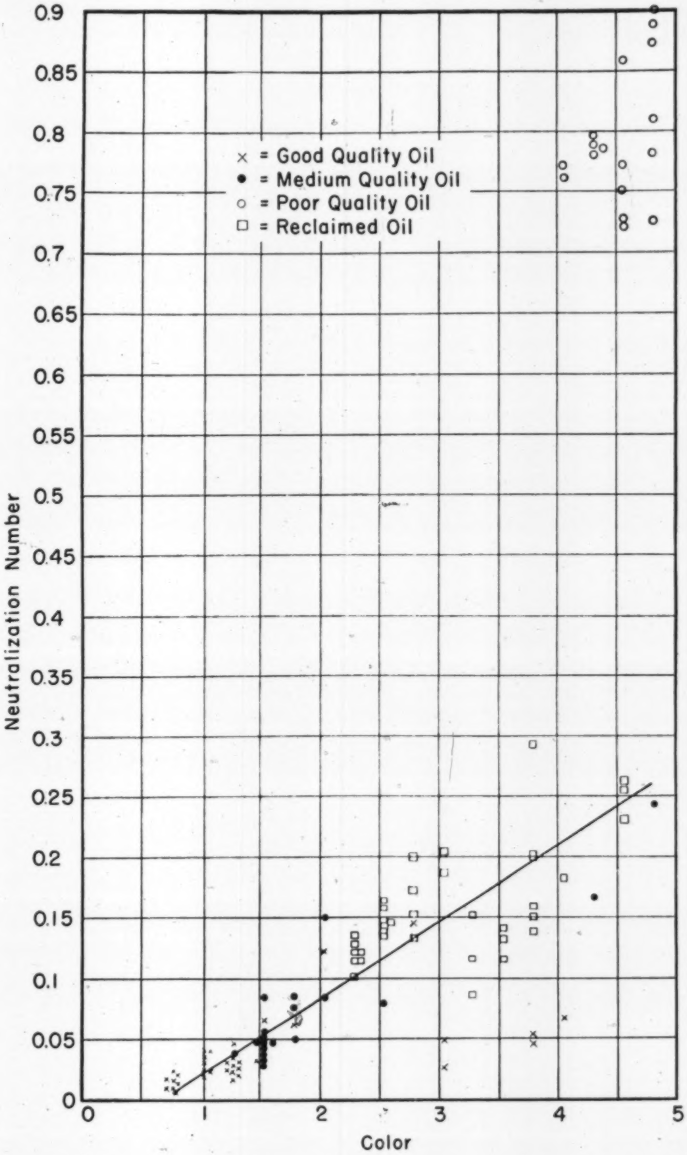

FIG. 23.—Correlation of the Oil Color and Neutralization Number which are Produced by Commercial Transformer Operation.

THE CORRELATION OF OIL TESTS

The sludge accumulation test results show little if any correlation with the sludge accumulation with color, neutralization value, and pressure oxidation, respectively. The fact that in some instances an improvement in the sludge accumulation property of an oil is observed during transformer operation in contrast to a stable or deteriorating change in the other oil properties, leads tentatively to the conclusion that the sludge accumulation test cannot be used as a gage of the chemical condition of mineral oil during transformer use.

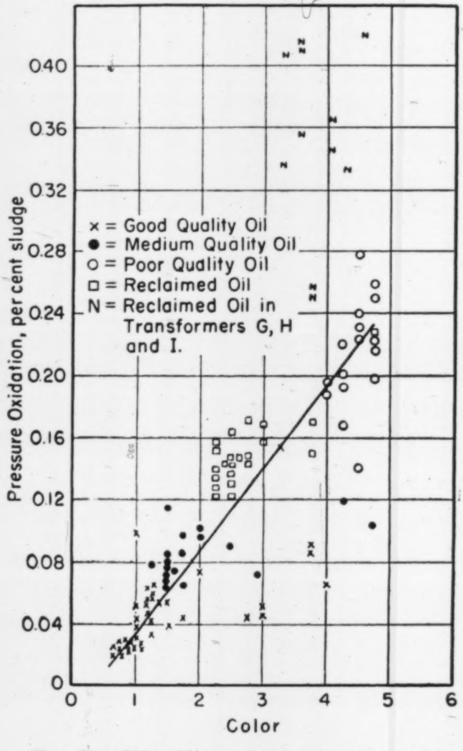

FIG. 24.—The Change in the Relation of Oi Color and Pressure Oxidation (Sludge) Values which are Produced by Commercial Transformer Operation.

Figure 22 illustrates the difficulty which has attended attempts to correlate the sludge accumulation results with the results of the pressure oxidation test. In the transformers illustrated, only good and acceptable oil has been used, yet the contrasting relationship of the two sludge tests is pronounced.

The study of the sludge accumulation test will be continued.

Oil Color Relation:

The relation of oil color change to the change in neutralization, pressure oxidation, and interfacial tension is illustrated in Figs. 23, 24, and 25, respectively. In all of the correlations there is a pattern. The oil color appears to increase linearly with increase in the neutralization and pressure oxidation values, but the exceptions to this relationship are striking and must be further studied. The color-neutralization number relation has no apparent value when the poor quality oils are considered (Fig. 23). On the other hand, when the relation of color to the pressure oxidation value is considered, the behavior of the reclaimed oils G, H, and I is abnormal. These are indicated by the letter *N* in Fig. 24. In both Figs. 23 and 24, there is shown to be a group of oils, different in each case, which, if the oil color were used as a cri-

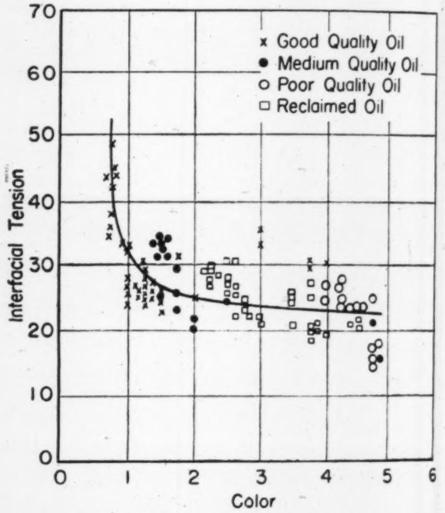

FIG. 25.—The Change in the Relation of The Oil Color and the Interfacial Tension Value of Mineral Oil which is Produced as the Result of Commercial Operation in Transformers.

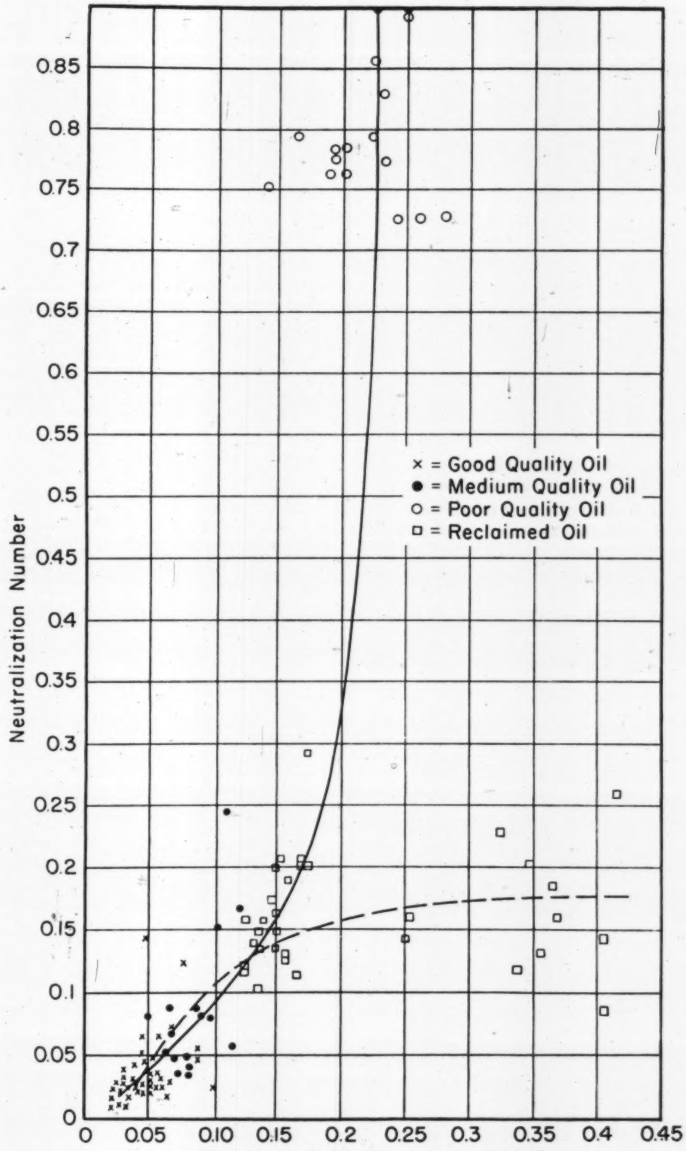

FIG. 26.—The Correlation of the Change in the Pressure Oxidation (Sludge) and the Neutralization Values of an Oil which is Produced as the Result of Commercial Transformer Operation.

terion of oil condition in transformer use, would be considered as in satisfactory condition, whereas their actual neutralization and pressure oxidation values would place them in a more seriously deteriorated category.

Figure 25 correlates oil color and the interfacial tension value. Here again, there is a pattern which indicates that a rapid drop in the interfacial tension value is to be expected with no substantial increase in color during the early stages of transformer use. At an interfacial tension value of about 25, however, the oil color increases rapidly with only small changes in the interfacial tension value. Since in the critical range of increasing color (above 2) and decreasing interfacial tension values (below 25), small changes in the interfacial tension values are of major significance, the spotty relationship of Fig. 25 must not be overlooked. For example, the "poor" oils illustrated have an oil color of $4\frac{3}{4}$. From the relation shown, the expected interfacial tension value would be 22, which on the basis of reported experience would indicate that the oil is still usable. Actually, the interfacial values reported were as low as 15. Such an oil would be considered as dangerous for continued transformer use. Were oil color the sole gage of the usability of these oils, erroneous conclusions might be drawn. It can only be concluded from the data reported to date, that the use of oil color as a gage of the chemical condition of oil in transformer use is promising, but further data are needed before reliance is placed on this oil property as protection against continuing a chemically hazardous oil in commercial use.

The Neutralization Number:

It has been generally recognized that the increasing neutralization number of an oil cannot be used as a gage of its sludging propensity. The rapidly increasing neutralization number characteristic of the oxidation of a highly refined nonsludging mineral oil is illustrative. Therefore, it is not surprising that there

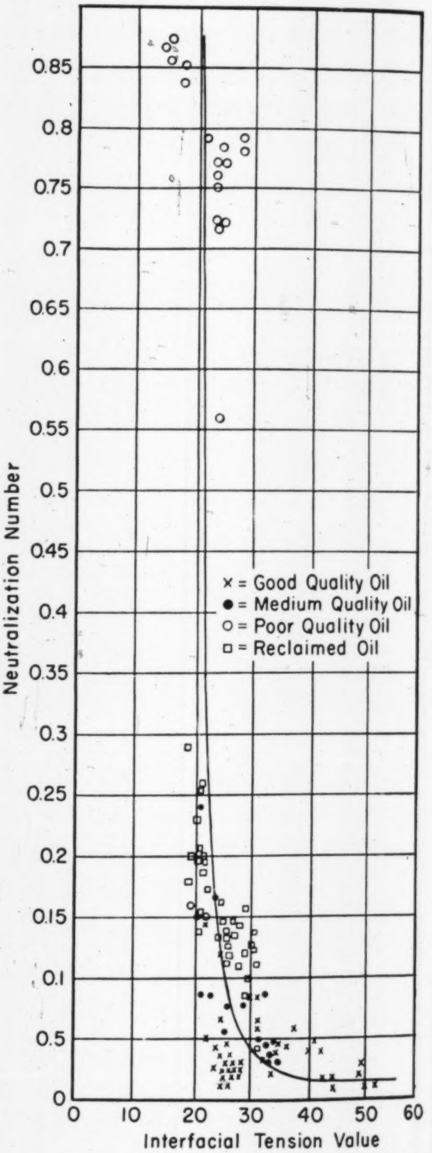

FIG. 27.—The Correlation of the Neutralization and the Interfacial Tension Values Observed in Mineral Oil During Commercial Transformer Operation.

are two contrasting relations which have been established in the reported data for the neutralization and the pressure oxidation sludge values. These are illustrated in Fig. 26. If the "poor" quality oils are considered, one relation is established between the neutralization number and the pressure oxidation. If the reclaimed oils are considered, another relation is established. In the former case, the neutralization number increases rapidly with no substantial change in the sludge value. In the latter instance, the sludge value increases rapidly with no substantial change in the neutralization number of the oil. Further test data and final study of the sludge accumulated on the core and windings of the transformers should give important information in these contrasting relationships.

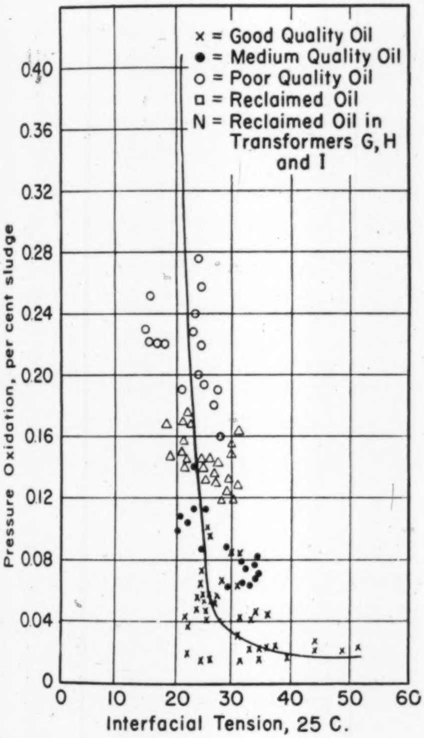

FIG. 28.—The Correlation of the Pressure Oxidation (Sludge) and Interfacial Tension Values which have been Observed in Mineral Oil During Transformer Operation.

The neutralization and the interfacial tension values are in good relationship (Fig. 27). Interfacial tension changes from the initially high value down to about 25 are accompanied by only minor changes in the neutralization number. Below about 25, minor changes in the interfacial tension value are accompanied by major changes in the neutralization number. Since general experience indicates that the hazard of continued transformer oil operation increases as the neutralization number approaches 0.7 or 1.0, the correspondingly small changes in the interfacial tension value and the difficulty inherent in the exact reproduction of any oil test property must be kept in mind if serious consideration is given to the use of the interfacial tension test as a protection against the continued transformer use of an oil in hazardous chemical condition.

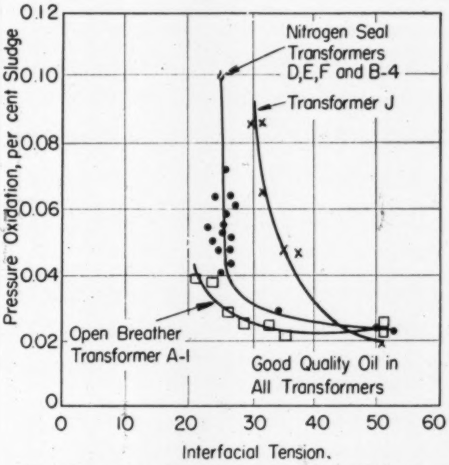

FIG. 29.—Showing the Contrasting Relationships Between Pressure Oxidation Sludge Value and the Interfacial Tension for Good Quality Oils During Commercial Transformer Operation.

The Pressure Oxidation Value:

The relation of the pressure oxidation to the color and neutralization values has already been discussed (Figs. 24 and 26).

Figure 28 relates the pressure oxidation and the interfacial tension test values. It will be observed that again there is a pattern but, again, the reliability of the relationship is obscured by the vagaries of the test data. As for the other relationships already observed, a drop in the interfacial tension from the initially high value to about 25 is not accompanied by any significant change in the pressure oxidation sludge. Below 25, however, minor changes in the interfacial tension value are accompanied by a marked increase in the sludging propensity of the oil as gaged by the pressure oxidation test. Further data are needed in order to explain the cause of the scattering of the test points.

The Interfacial Tension Test Values:

The relation of the interfacial tension test to the oil properties of color (Fig. 25), neutralization (Fig. 27), and pressure oxidation (Fig. 28) has already been discussed. In general, a good pattern of relationship has been established in each case. This relationship indicates that a change in the interfacial tension from the initial value to about 25 is without practical significance but minor changes below 25 are accompanied by major changes in the other oil properties. Further test data are needed before the interfacial tension test can be accepted as a reliable gage of the chemical condition of an oil in transformer use. This is illustrated in Fig. 29, which correlates the interfacial tension and the pressure oxidation sludge values for the acceptably good quality oil in the open-breather and nitrogen-seal transformers. As illustrated, an interfacial tension value of 25 would indicate (1) a satisfactory condition of the oil in the open-breather transformer A-1, (2) a "runaway" condition of the sludging propensity of the oil in the nitrogen-seal transformers D, E, F, and B-4, and (3) a still more hazardous condition of the oil in transformer J on the basis of the pressure oxidation-sludge relationship. It is hoped that the further accumulation of oil test data and the final examination of the core and coils of the test transformers will clarify the relationships such as are illustrated in Fig. 29.

RECAPITULATION

The Significance of the Oil Tests:

In transformer operation when oxidation is possible, common experience indicates that the oil will darken in color, increase in neutralization value, increase in sludging tendency, and decrease in interfacial tension value. In transformers where oxidation is reduced or impossible because of the absence of oxygen, such as in the nitrogen-seal transformers, these changes in oil color, neutralization, sludging propensity, and interfacial tension are likewise reduced or eliminated. Experience, however, does not indicate that the oil under either of these conditions of use will be characterized by a continuously improving resistance to oxidation and sludge formation. Since the sludge accumulation test gives frequent evidence of such an improved sludge resistance during the transformer operation as already described, further consideration of this test as a gage of the chemical condition of the oil in service is postponed until more data have been accumulated and the final condition of the transformer core and coil has been determined.

Since excessive sludge formation is the basic problem which confronts the operator of oil-filled transformers and is the oil problem on which the hazard to continued and uninterrupted transformer operation is predicated, an oil test—whatever nature it may be—must ultimately be associated with the sludge actually deposited in the transformer. A successful oil test must necessarily be the one which will tell the operator in a simple and reliable manner the degree of oil sludge hazard which confronts him should he continue his oil-filled transformer in service. From this standpoint, none of the oil tests considered appears to be free from serious criticism.

The tests which appear to be most promising at present are the tests for the pressure oxidation sludge and the interfacial tension values. Each is subject to criticism in our present state of knowledge. The pressure oxidation test is said to be operated under conditions of oxidation which are too extreme. Yet it shows none of the anomalies characteristic of the milder sludge accumulation test. The interfacial tension test is said to be more directly related to the soluble oxidation products of the oil than to its tendency to form sludge. Yet it offers promise of use as a gage of the sludging tendency as affected by the transformer operation of the type of oil generally used in American practice. If further work demonstrates that either the interfacial tension test or the pressure oxidation sludge value can be definitely correlated with the chemical condition of the oil during transformer use as viewed from the hazard of sludge formation and accumulation, a real contribution toward the solution of the operator's oil and transformer maintenance problem will have been made.

TABLE III.—EVALUATION OF OIL BEHAVIOR.

Transformer and Oil Quality	Color	Neutralization Value	Sludge Accumulation	Pressure Oxidation	Interfacial Tension
A-1 (good)	stable	stable[a]	stable	stable	poor[b]
A-2 (poor)	stable	rises	falls	rises	poor[b]
A-3 (medium)	stable	rises	falls	stable	poor[b]
B-4 (good)	stable	stable	stable	stable	stable[c]
B-5 (poor)	stable	falls	stable	rises	poor[a]
B-6 (medium)	stable	stable[a]	stable	stable	good[d]
C-7 (good)	rises	rises	stable	stable	poor[b]
C-9 (medium)	rises	rises	falls	stable	poor[b]
D (new)	stable	stable	rises	stable	good[d]
E (new)	stable	stable	rises	stable	poor[b]
F (new)	stable	stable	rises	stable[a]	good[d]
G (reclaimed)	stable	rises	falls	rises	good[d]
H (reclaimed)	rises	rises	rises	rises	poor[b]
I (reclaimed)	stable	rises	falls	stable[a]	poor[b]
J (new	rises	stable[a]	rises	rises	stable[c]
K (reclaimed)	stable	rises	falls	stable	poor[b]
L (reclaimed)	stable	stable	falls	stable	good[d]
M (reclaimed)	rises	rises	stable	stable	poor[b]

[a] Indicates only a slow increase.
[b] Final value less than 25.
[c] Final value 30 or higher.
[d] Final value 25 to 30.

In Table III there is summarized the changes in the various oil properties which occurred during transformer operation to date. Many of the changes observed in one oil property are conflicting with the changes simultaneously occurring in one or more of the other oil properties. In formulating this table, the criterion for oil classification has been the tendency of the oil to change in the property stated. This has been used in a qualitative sense only, and no consideration has been given to the initial quality in the oil property used. The hazard of this is recognized. A review of Table III shows that on the basis of resistance to change, the various oil tests would classify the oils as follows:

All tests indicate that the following oils, operating in nitrogen-seal transformers, are chemically stable:

B-4	(good quality)
B-6	(medium quality)
D	(new)
F	(new)
L	(reclaimed)

All tests agree that the following oil operating in a water-cooled transformer is showing chemical instability:

H (reclaimed oil)

The remaining 12 oils are classified variously by the different tests as follows:

On the basis of all practical experience, the oil characterized as of poor quality would be expected to be so classified on any test property taken during the transformer operation. This oil is used in two transformers, A-2 (open-breather) and B-5 (nitrogen-seal). The oil shows the expected instability in both types of transformers on the basis of the neutralization, pressure oxidation, and interfacial tension tests. The color test indicates stability.

On the other hand, those oils which have been classified as of "good" quality or "new" quality on the basis of oil refining and transformer experience would be expected to show substantial stability during transformer operation for a period as short as 42 months. Such oils are those in transformers A-1, C-7, E, and J. Of these oils, all are classified with the expected stability on the basis of the pressure oxidation test with the exception of J. The color and neutralization tests, however, agree on the classification of only oils A-1 and E as showing the expected stability, and on the basis of the interfacial tension test, only the oil in transformer J is classed as showing chemical stability. Despite the more favorable agreement of the pressure oxidation test results with commercial experience with regard to oil quality performance and the less favorable agreement of the interfacial tension test, final conclusions concerning the merit or lack of merit of any of the oil tests as a gage of oil performance in actual transformer use, must be held in abeyance until further data are accumulated and until the results finally are correlated with the sludge actually accumulated in the transformer which constitutes the hazard toward the elimination of which all oil tests are directed.

GENERAL SUMMARY

The chemical instability of an oil of acknowledged inferior initial quality can be detected by most of the oil tests normally used in the acceptance and control of American mineral transformer oil. With oil of good and accepted quality, no one test can be accepted at present as a proper protective gage for the evaluation of the sludging hazard which is presented by the continued transformer use of a highly oxidized oil. The pressure oxidation test shows promise. The interfacial tension test has its advocates. Until more extensive operational oil test data are secured, however, and until such data are carefully correlated with the sludge actually accumulated within the transformer as the result of such operation, final conclusions concerning the merits of the various oil tests must be held in abeyance.

The continued work of the Subcommittee IV of A.S.T.M. Committee D-9, includes the accumulation of these important test data.

SIZE AND BORDER CONDITIONS OF TEST SPECIMEN IN THEIR RELATION TO RESULTS OF FIRE TESTS*

By S. H. Ingberg[1]

Synopsis

Fire tests are designed to indicate the safety or protection given by building constructions when exposed to fire. This may be limited by failure under load or collapse from excessive lateral deflection, or by ignition of materials against the side not exposed to fire from high temperatures or passage of hot gases or flame through a construction such as a fire or party wall.

It is essential that fire tests be made in general with specimens representative in size of panels or units of construction applied in buildings. Lateral deflection of walls exposed to fire on one side varies approximately with the square of the height between supports and inversely with the thickness. The time required under the conditions of the fire test to attain a given temperature rise on the side not exposed to fire or within the construction is dependent on the 1.7 power of the respective thicknesses or distances from the fire-exposed surface.

Expansion of the heated construction induces high stresses that may cause general or local failure, and hence the specimen should be tested under conditions representative in this respect of those present for such constructions when exposed to fire in buildings. The lateral dimensions of the specimen need be such that temperatures over a representative portion of it will not be appreciably affected by cooling effects from the borders.

Limited extension and interpolation can be made of results of fire tests by applying established relations such as that between thickness, or other applicable dimension of the cross-section, and fire-resistance period.

The size of test constructions required in the accomplishment of fire tests is within the usual range of size for comparable building members. Thus, the height of column, wall and partition specimens is based on the distance between floors, and the width or length of wall, partition and floor specimens, on the spacing of columns, beams, and other supporting members. Present standard methods for conduct of fire tests[2] require not less than 9 ft. for height of column specimens and height and width of wall and partition specimens, with the further requirement for these latter that the area be not less than 100 sq. ft. For floor and ceiling specimens the minimum area exposed to fire is set at 180 sq. ft. with no lateral dimension less than 12 ft. A provision is made for tests with smaller specimens only where the conditions of use limit the construction to lower dimensions than those otherwise required.

It is thus seen that the fire test of building constructions is of the full-scale type, although the required specimen sizes are not necessarily up to the larger or maximum sizes of units entering into building construction. From the standpoint of achieving representative results there are advantages in this type of test, the import of some of which will be outlined as based on specific performance characteristics in fires and fire tests. Others can be taken as common for this general type of test, such as the likelihood that the results will reflect the effect of incidental variations in quality of material and workmanship better than with a smaller specimen. Also, particularly in a new experimental field, conditions not readily anticipated may have a bearing on results, indicating the general advantage of specimens representative in size as well as on other details.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] Principal Engineer, Fire Resistance (Retired), National Bureau of Standards, Washington, D. C.

[2] A.S.T.M. Standard Methods of Fire Tests of Building Construction and Materials (E 119 - 47), 1947 Supplement to the Book of A.S.T.M. Standards Part II, p. 191.

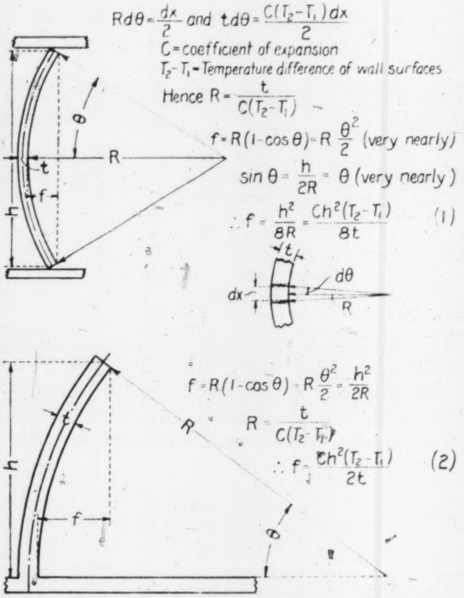
$R d\theta = \frac{dx}{2}$ and $t d\theta = \frac{C(T_2 - T_1)dx}{2}$
C = coefficient of expansion
$T_2 - T_1$ = Temperature difference of wall surfaces
Hence $R = \frac{t}{C(T_2 - T_1)}$
$f = R(1 - \cos\theta) = R\frac{\theta^2}{2}$ (very nearly)
$\sin\theta = \frac{h}{2R} = \theta$ (very nearly)
$\therefore f = \frac{h^2}{8R} = \frac{Ch^2(T_2 - T_1)}{8t}$ (1)
θ
R
t
f
h
t
$d\theta$
dx
R
$f = R(1 - \cos\theta) = R\frac{\theta^2}{2} = \frac{h^2}{2R}$
$R = \frac{t}{C(T_2 - T_1)}$
$\therefore f = \frac{Ch^2(T_2 - T_1)}{2t}$ (2)
R
t
h
f
θ

FIG. 1.—Deviation of Deflection Formulas.

The full-scale test involves a relatively large cost for equipment, testing, and test specimens, that has severely restricted the volume of data that has become available from results of fire tests. Inquiry might accordingly be made on the feasibility of supplementing the results from the full-scale tests with those from tests of smaller specimens. Information on the effect of size on performance in fire tests may accordingly give indications on the extent to which this might be realized.

The safety or protection given by building constructions in fires and fire tests may be limited by failure under load or collapse from excessive deflection, a temperature rise on the side not exposed to fire that may ignite combustible material in contact therewith, or ignition of such materials by passage of flame or hot gases through cracks or openings resulting from the fire exposure. The individual effects of the fire exposure may combine in causing failure. Thus, deflection and reduction in strength of materials from temperature difference or increase may result in failure under load, and deflection combined with stresses induced by restraint may cause dislodgement or crushing of parts of the construction with attendant occurrence of cracks and openings. In the present paper the individual effects of the fire exposure will be segregated as far as possible in the consideration of the effect thereon of size and border conditions of the test specimen.

SOME EFFECTS OF DIMENSIONS AND BOUNDARY CONDITIONS ON PERFORMANCE UNDER FIRE EXPOSURE

Lateral Deflection of Walls and Partitions:

A building wall or partition serves the purpose of restricting the spread of fire when exposed on only one side. The consequent temperature difference between its faces induces lateral deflection, the extent of which is dependent also on its dimensions and the expansion properties of the material. In Fig. 1 (upper) a slab supported on two opposite edges is shown that is assumed under a temperature difference between its two faces of T_2–T_1. Based on the small section (right) in Fig. 1, the radius of curvature, R, of the deflected slab is obtained in terms of slab thickness, coefficient of expansion, and temperature difference. Being that R is large in comparison with the height and thickness of the slab, a simple expression is obtained for the deflection

$$f = \frac{Ch^2(T_2 - T_1)}{8t} \quad \ldots\ldots\ldots\ldots(1)$$

which gives it directly in terms of the slab dimensions. Similarly, for a slab free at vertical and top edges, Fig. 1 (lower), the deflection at the top is expressed by,

$$f = \frac{Ch^2(T_2 - T_1)}{2t} \quad \ldots\ldots\ldots\ldots(2)$$

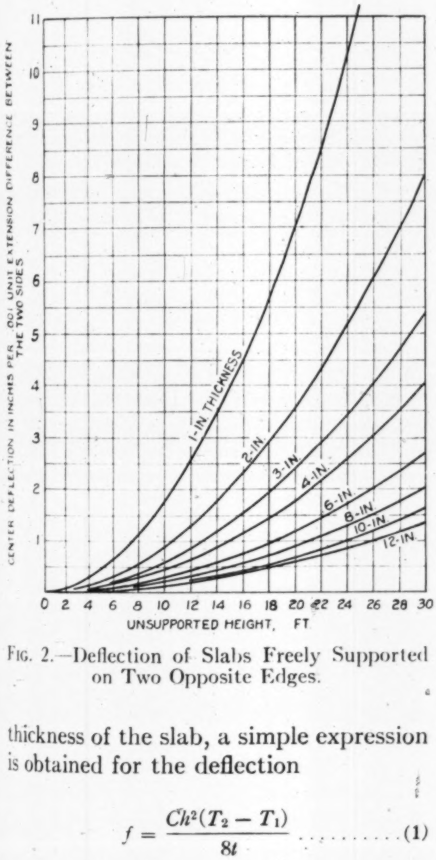

FIG. 2.—Deflection of Slabs Freely Supported on Two Opposite Edges.

Very little approximation is involved in Eqs. 1 and 2 compared with more nearly precise expressions, one for Eq. 1 being,

$$f = R(1 - \cos\theta) = R(1 - \sqrt{1 - \sin^2\theta})$$

$$= \frac{t}{C(T_2 - T_1)}\left[1 - \frac{1}{2t}\sqrt{4t^2 - C^2h^2(T_2 - T_1)^2}\right]$$

In Fig. 2 an evaluation for deflections according to Eq. 1 is given for a difference in unit extension between the two faces of 0.001, which for coefficient of expansion of 0.00001 per deg. Cent., is equivalent to a temperature difference of 100 C. This applies accordingly for the center deflection of walls and slabs freely supported on two opposite edges and otherwise not restrained. For the condition of restraint at one edge and the others free, Eq. 2 applies and the deflection at the edge opposite the one under restraint will be four times the corresponding values given in Fig. 2.

Deflection data from fire tests of walls and partitions are given in Tables I and II to indicate the extent to which Eqs. 1 and 2 apply and the general agreement of test data with theoretical relations.

The walls and partitions for which results are given in Table I were of conventional designs of burned clay structural tile, nearly all with cells thereof set vertical and all without plaster or other finish. They were tested either fully or partly restrained within the test frames, under load, or unrestrained at vertical and top edges. The loading of 120 psi. on those tested under load was about 25 per cent of the strength of the masonry and less than 10 per cent of the average compressive strength of the tile units.

In the test of 4-in. partition No. 2a of shale tile, ½ in. was allowed for expansion, but after 12 min. this was taken up by the expansion and deflection of the wall. The lower deflection of partition No. 4 was without doubt due in part to the lower expansion of the fireclay material. One 10 ft. by 10 ft. 4-in. wall of surface clay tile of similar design and tested restrained, failed at 14 min. because of damage from expansion stresses and deflection.

TABLE I.—DEFLECTIONS OF CLAY STRUCTURAL TILE WALLS AND PARTITIONS.
(Wall material, multi-celled burned-clay rectangular units. Length of walls, 8, 10, or 16 ft.)

Type of Clay	Restraint or Load on Gross Area, psi.	Wall Height, ft.—in.	Nominal Wall thickness, in.	Number of Tests	Maximum Lateral Deflection		$F - T_1$, deg. Cent.	$T_2 - T_1$ Computed, deg. Cent.	$F - T_2$ Computed, deg. Cent.	References[a]
					Average from Tests, in.	Time, min.				
Shale	Partly restrained	10—0	4	1 (No. 2a)	2.50	30	...	...	...	**(1)**
Fire clay	Set-in restrained	10—0	4	1 (No. 4)	1.50	35	...	...	...	**(1)**
Surface clay	Built-in restrained	10—0	6	1 (No. 17)	4.00	60	...	...	...	**(2)**
Fire clay	Built-in restrained	10—0	6	1 (No. 18)	2.50	30	...	...	...	**(2)**
Shale	120	10—4	8	3	1.38	76	890	575	315	**(3)**
	Unrestrained	11—0	8	1	6.25 (at top)	167	800	575	225	**(3)**
	Built-in restrained	11—0	16	1	0.90	225	950	660	290	**(3)**
Surface clay	120	10—4	8	3	1.03	125	910	510	400	**(3)**
	Unrestrained	11—0	8	1	4.37 (at top)	222	800	475	325	**(3)**
Fire clay	120	10—4	8	4	1.16	91	880	675	205	**(3)**
	Built-in restrained	11—0	8	5	1.05	67	865	550	315	**(3)**
	Built-in restrained	11—0	12	1	0.90	90	930	710	220	**(3)**
	Unrestrained	11—0	12	1	4.65 (at top)	195	920	910	10	**(3)**
	Built-in restrained	11—0	16	4	0.95	316	1045	1000	45	**(3)**
	Unrestrained	11—0	16	1	3.40 (at top)	365	1030	895	135	**(3)**

[a] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1077.

TABLE II.—LATERAL DEFLECTIONS OF CONCRETE MASONRY WALLS AND PARTITIONS. ALL WALLS 6 FT. HIGH AND 5. FT. 6 IN. WIDE.

Wall Material	Coarse Concrete Aggregate	Load on Gross Area, psi.	Nominal Wall Thickness, in.	Number of Tests	Maximum Lateral Deflection		Average Time from Start of Tests, min.	References[a]
					Average from Tests, in.	Average (computed), in.		
Cored units	Crushed limestone or calcareous pebbles	80	4	3	0.56	0.80	36	**(5)**
		80	8	58	0.38	0.40	49	**(5)**
		80	12	5	0.24	0.21	42	**(5)**
	Siliceous pebbles	80	4	1	0.94	1.09	60	**(5)**
		80	8	9	0.52	0.59	53	**(5)**
	Crushed expanded burned shale	80	4	2	0.13	0.25	21	**(5)**
		80	8	25	0.10	0.11	21	**(5)**
		80	12	4	0.07	0.03	22	**(5)**
Solid concrete	Calcareous pebbles	500	4	1	0.53	0.67	36	**(6)**
		400	6	2	0.51	0.45	42	**(6)**
		400	8	1	0.44	0.33	48	**(6)**
	Siliceous pebbles	500	4	1	1.28	0.82	66	**(6)**
		400	6	3	0.63	0.58	64	**(6)**
		400	8	1	0.56	0.43	60	**(6)**
	Crushed expanded burned shale	500	4	1	0.19	0.15	18	**(6)**
		400	6	2	0.16	0.13	18	**(6)**
		400	8	1	0.19	0.09	24	**(6)**

[a] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1077.

Walls 17 and 18 **(2)**[3] of 6-in. tile having two cells in the wall thickness, were built solidly into heavy restraining frames and the deflections from temperature difference were without doubt considerably increased by the general expansion of the wall. After the wall deflection exceeds one-sixth of the wall thickness, the center of the deflected section will be outside of the middle third of the base, but stability will be maintained considerably beyond this point because of tensional resistance, induced resisting moments at the borders and shifting of the center of the bearing thereon toward the fire-exposed side (Fig. 1). Even so, for deflections much exceeding this limit, the increment from axial extension is without doubt proportionately greater than for lower deflections. The failure of these two walls was, however, due to high temperatures on the unexposed side and not from general or local collapse caused by lateral deflection. Failure from expansion and deflection effects, earlier than would have obtained because of high temperatures on the unexposed side, occurred in this series for some walls of 3-, 4-, and 6-in. tile having one cell in the wall thickness. These were also tested restrained, on height of 10 ft., the length being 16 ft.

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[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1077.

In the series, the results of which are reported in a Bureau of Standards Research Paper (3) there was no failure that can be directly attributed to lateral deflection, although, in conjunction with stresses induced by expansion, it contributed without doubt to failure on other particulars. No walls were, however, of less thickness than 8 in. For one comparison obtained for center lateral deflection of loaded as compared with restrained walls, the latter had lower average deflection, 1.05 in. (reduced to 0.93 at 10 ft. 4 in. height) as compared with 1.16 in. for the loaded walls. It may be noted that the loaded walls were free at the vertical edges which might account in part for their relatively higher deflection. The center deflections were low considering wall thickness and height, and hence the restraint of expansion from the loading or the restraining frame could not have added much to the deflection attributable to temperature difference between the two faces of the walls. The center deflections of the 12-in. and 16-in. walls were higher in comparison with those for the 8-in. walls than the inverse ratio of thickness (Eq. 1), which might be attributable in part to the longer time from the start of the test when the maximum deflection occurred and their higher heat insulation with consequent higher temperature difference between the two faces for the thicker walls.

The outward deflection at the top of the unrestrained 8-in. walls of shale and surface clay tile was on the average very nearly four times the average center deflection of comparable loaded walls, as reduced to the same height basis. For the 12-in. and 16-in. thicknesses the data limits the comparison to results with unrestrained and restrained walls of fire-clay tile, the average ratio of which is 4.3. A ratio higher than four might be expected on account of the relatively low deflection of restrained walls of 8-in. or greater thickness, as compared with that of loaded walls with free vertical edges. Actually, as verification of theoretical relations, these ratios should not necessarily be taken at full value. It is difficult to establish representative fire test conditions for unrestrained walls since there is curvature in horizontal as well as vertical planes. In an attempt to minimize the effect of the former on the deflection of the top of the 8-in. walls, pilasters were built into them near the side edges, the effect of which, while in the right direction, was somewhat indeterminate. The 12-in. and 16-in. unrestrained walls were tested without pilasters and the curvature of the top deflected edge

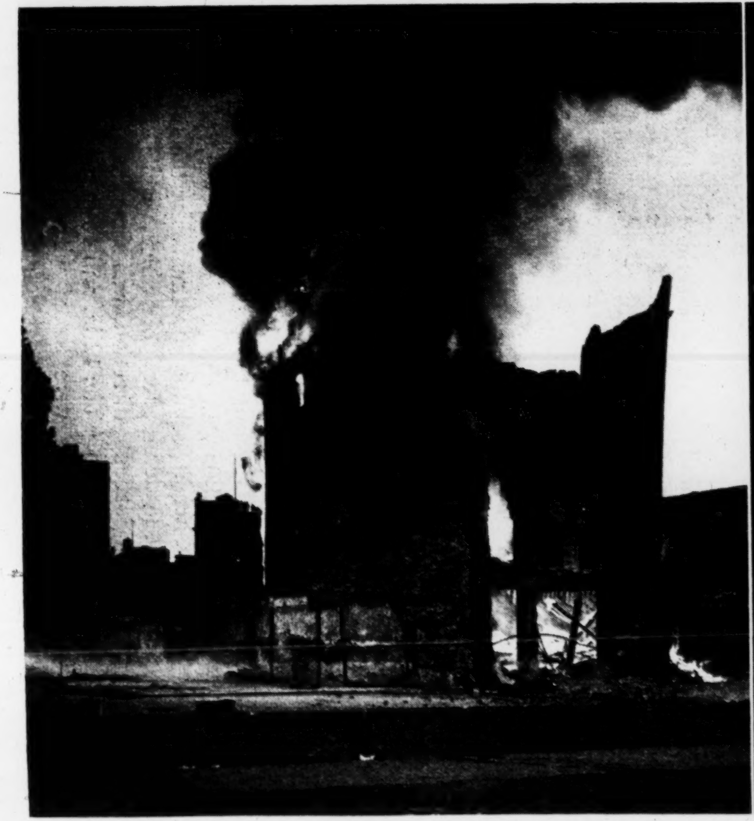

FIG. 3.—Collapse of Walls in a Fire Test of a Building of Non-Fireproof Interior Construction.

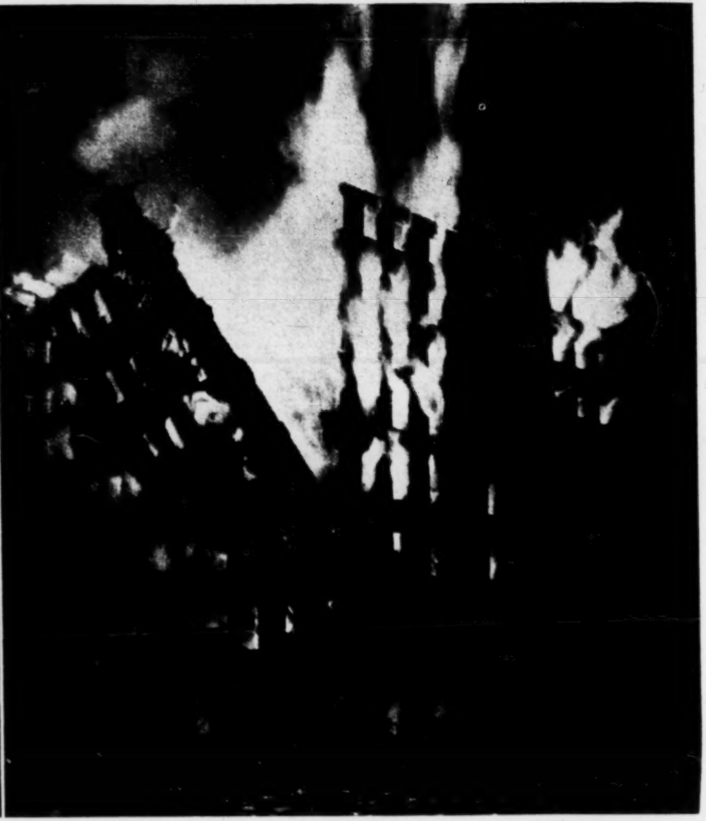

FIG. 4.—Collapse of Walls in a Building Fire (Courtesy of International News Service).

introduced some degree of uncertainty as to whether the deflection was representative of that of a long wall for which the top deflected edge can be assumed as being without curvature.

There was no failure due to deflection for the unrestrained walls, although the results indicated that such failure might occur with such wall constructions in building fires. Figure 3 shows failure of exterior walls in a fire test with a 5-story building having unprotected wood-joist interior construction (4). This test was conducted in conjunction with razing operations for the site, the building being loaded with scrap lumber as combustible contents. The walls were 22 in. thick in the ground story and 13 in. at the top, but failure thereof from outward deflection began during the first half hour of the test, soon after interior construction collapsed. Figure 4 shows similar failure in a building fire, many of which have occurred with buildings having exterior masonry bearing walls and interior wood or unprotected metal framing.

No direct comparison of experimental deflection data and corresponding values computed according to Eqs. 1 and 2 is possible since the temperature of the fire-exposed face of the wall is not known. It can be assumed to be considerably below the furnace temperature, the difference decreasing with the length of fire exposure and the thickness of the wall. In the tests reported under (3) the average temperatures of the unexposed surface were fairly well determined with uncovered fine-wire thermocouples in contact with the surface. The difference between them and the average indicated furnace temperatures, (F–T_1), is given in Table I for tests of 8-in. or thicker walls.

The next column gives the computed temperature difference (T_2–T_1) between the exposed and unexposed faces of the wall, based on Eq. 1, or,

$$T_2 - T_1 = \frac{8fl}{Ch^2}$$

for the center deflection, and from Eq. 2 for the deflection at the top of unrestrained walls,

$$T_2 - T_1 = \frac{2fl}{Ch^2}$$

The coefficient of expansion of the tile walls, based on expansion tests made of the burned-clay material in the range of temperatures here of interest (3, p. 23), was taken as 0.00001 for those of shale tile, 0.0000085 for surface clay, and 0.000007 for fireclay tile walls. The difference given in the last column is accordingly that computed as obtaining between the indicated furnace temperature and the temperature of the fire-exposed surface, based on the relations given in the above formulas and the measured deflections.

Differences between indicated furnace temperatures and fire-exposed surface temperatures of 300 C. and 400 C. may well obtain during the second hour of the standard fire test since the former will be in the range 900 to 1000 C. and the wall surface no more than dull red. In the later stages of the test, of present interest from 4 to 6 hr. after the start, the average indicated furnace temperatures will be between 1100 C. and 1200 C. and a wall surface light red to nearly white might correspond to temperatures of 900 to 1100 C. The resulting temperature differences would correspond in general with the trend of differences given in the last column of the table, decreasing as they do for the thicker walls and longer intervals after the start of the test. It is also to be noted that these differences are sensitive to variations in the computed T_2–T_1 temperature difference and that the latter varies inversely with the second power of the wall height. Computations made with the exponent varying below and above 2 indicate that as applied to the results of this series of tests it must be within the range 1.8 to 2.2 if rather obviously inconsistent relations between furnace temperatures and computed fire-exposed wall surface temperatures are to be avoided.

In Table II are given lateral deflections of concrete masonry walls from the results of two series of tests. They are grouped for each series according to the course aggregate for the concrete. All walls were 6 ft. high, $5\frac{1}{2}$ ft. wide and subjected to fire under load with free vertical edges. The vertical expansion as well as the lateral deflection was reported. Since the deflection causes the bearing to be shifted largely to the fire-exposed edge and the applied loads are low in relation to the ultimate strength of wall and units, and further that the difference between the length of the deflected wall and its chord is very small, the expansion per foot of height can be taken as expressed by:

$$e = 12C(T_2 - T_1)$$

where T_2 is the temperature of the fire-exposed face and T_1 the initial temperature, which is here taken as the same as the temperature of the unexposed face at the time the maximum deflection is attained. It is noted that the temperature of the unexposed free face is lower than the temperature measured on it under the asbestos pad prescribed in the standard fire testing procedure, and within the first hour of the test, when maximum deflections were generally attained, had risen no more than about 25 C. above the initial temperature. Substituting in Eq. 1 for $C(T_2-T_1)$ from the above expression, the following relation between lateral deflection and expansion is obtained:

$$f = \frac{eh^2}{96t} \quad \text{..............(3)}$$

Deflections thus computed are given in Table II. It is seen that they agree fairly well with experimental values and quite closely where the average is based on 25 or more individual results. Practically all would come into agreement with an exponent for h chosen within the range 1.9 to 2.1. The decrease in deflection with increase in wall thickness is less than would obtain according to Eq. 1. The deflection of the walls for which siliceous aggregate was used in the concrete conformed most nearly with the theoretical relation. Their deflections in the 4-in. thickness was on the average about twice that for the same wall thickness with concrete or concrete units made with calcareous aggregates, but for the 8-in. thickness they were only about 30 per cent higher. There was no failure from lateral deflection of any of the walls or partitions in these two series as tested on the height of 6 ft.

The deflections of the walls for which the concrete or concrete units were made with expanded burned-shale aggregate were between one third and one fourth of those of walls of comparable thickness made with calcareous aggregates. Corresponding low deflections were obtained in these tests with walls of concrete units made with cinder and slag aggregates.

DEFLECTION OF FLOOR SLABS

The greater part of the deflection of floor slabs, as exposed to fire on one side, is due to temperature difference between the faces, at least up to the stage approaching failure under load. For slabs freely supported on two opposite edges, the deflection will be governed by the general relation expressed in Eq. 1 as concerns the effect of thickness and span length on deflection. This condition, however, is seldom present since there will in general be support, or support and restraint, at the border on all sides. For the freely supported slabs the deflection due to temperature difference will not induce large stresses or strains, but with continuity or restraint at the border supports, the materials and reinforcing elements near them will be severely stressed thereby and the deflections will be lower than for the freely supported condition. Accordingly, it appears necessary that the test specimens of floor constructions should embody a representative degree of continuity and restraint, which may be accomplished by inclusion of beams or girders and close contact or contact and attachment to a bordering rigid restraining frame. Since deflection and restraint affect the stability of facing and protective material on the fire-exposed side, it appears important that the lateral dimensions of the specimen should approach those of floor panels in buildings. With results from tests thus made as a basis, much information, such as on effect of thickness, might be obtained with smaller specimens.

SIGNIFICANCE OF RESTRAINT AT THE BORDERS AS A TEST CONDITION

There have been indicated above, certain effects of restraint of expansion at the borders of wall, partition, and floor specimens. The restraint on wall and partition panels built between horizontal and vertical supporting members of the building will be limited in a degree by the rigidity of these members and the effect of the fire exposure thereon. Incidental conditions such as imperfect joints with the surrounding construction may also afford some relief. However, the expansion under fire exposure of members such as partitions may be quite large—in the range $\frac{1}{2}$ to 1 in. for some materials in the height of one story. It accordingly appears that it is justified to impose a considerable degree of restraint on such constructions during fire tests, short of the full restraint it is in any case difficult to accomplish in test equipments.

In fire tests of solid floor slabs and supporting beams, a test condition of full or nearly full restraint is in general representative since any inner panels thereof exposed to fire in buildings would be restrained by the surrounding slab. It has been observed that the outer panels of floor slabs suffer less damage in fires than the inner panels. However, if representative only of use in small areas, such as in detached private dwellings, the fire test might be made with the slab under less restraint or no restraint.

Columns are tested under normal working loads, but under fire conditions in buildings, individual columns subjected to higher fire exposure than others in the same story may be further restrained by the increased reactions from resistance in continuous floor construction supported by the column. The effect is difficult to allow for and may be offset by supported live loads lower than the design load at the stage of the fire when failure under load may occur.

The material near the outside of the column is restrained by tensional resistance in the material at lower temperature nearer its center. Accordingly, the outer protective material should be restrained from expanding more than the column shaft which may be accomplished by bearing against plates or slabs secured at the column ends.

EFFECT OF THICKNESS

It has been established on the basis of principles of heat conduction that for homogeneous slabs of the same thermal properties, the time required for a given temperature rise on one face, as due to a constant temperature on the other, varies with the square of the thickness (**7, 8**). This assumes no heat loss at the unexposed face, a condition sufficiently achieved for the present purpose with the felted asbestos pads under which the surface temperatures are determined. The same applies for the temperature rise at the axis of a long cylinder as subjected to a constant temperature on its surface. However, the exposing temperature in the standard fire test is not constant but rises at a rate which after the first 2 hr. is about 83 C. (150 F.) per hr. During the first part of the test the rise is more rapid but not as steep as indicated by the standard furnace curve on account of the thermal lag of the pyrometers and radiation effects (**9**).

With such rising temperature on one side the thicker member requiring the longer time for a given temperature rise to obtain as a result thereof would be subjected to a higher average temperature for the period than a thinner member over a shorter period. Comparison of results of fire tests of constructions, nominally comparable except for thickness, have indicated the effect of the rising exposing temperature in that the exponent for the thickness has a value near 1.7 instead of the second power applicable for a constant exposing temperature (**10**). This relation applies not only for solid constructions but also approximately for those with air spaces if the sections are similar and the thicknesses not too far different. While air spaces have some value (**10**) for similar sections, their effect will largely cancel out in the comparison and hence the relation can in general be expressed by,

$$R_2 = R_1 \left(\frac{V_2}{V_1}\right) 1.7 \qquad (4)$$

where R_1 and R_2 are the fire endurance periods corresponding to volumes of solid material per unit of area of V_1 and V_2, respectively.

If the fire resistance of a construction is limited by ability to carry load or protect load-carrying elements or members, the temperature rise within it may be of interest. On the same basis as for surface temperatures it has been determined that for a constant higher temperature at the hot surface, the times required for any two points to reach the same temperature rise are proportional to the squares of their distances from the surface (**7**). This also applies for the times required to reach the same temperature rise at different depths in a cylinder. With the rising temperature of the standard furnace test, the relation would be given more nearly by the 1.7 power of the ratio of depths.

TEMPERATURE GRADIENTS NEAR THE BORDER

The test specimen should be of such size that temperatures will obtain over a representative portion thereof that are not appreciably affected by cooling from the borders. What the temperature gradients are within and on the surface of the specimen because of such cooling effects have not been well determined experimentally, a matter complicated by attendant gradients in furnace temperatures. A specimen such as a column is heated by surface contact with furnace gases and radiation and loses heat largely at the ends through conduction to the bearing blocks and other parts of the loading equipment. The temperature gradient is thus dependent on the relation of surface coefficient of heat transfer times surface area to coefficient of heat conductivity times the area of the cross-section. Theoretical solutions giving the variation in the temperature of the specimen as the border is approached are informative, but their application is limited by uncertainty as to values of thermal constants at the temperatures and under the conditions incidental to fire tests.[4]

Evaluations based on a possible range in the value of the constants indicate that for test columns representative of the usual range in material and design, and of the smaller range of size applied in buildings, the border effect is not large at 1-ft. distance from the protection applied over the bases of the column, and at 1½ to 2 ft. it may be within the range of incidental variation applicable for this type of test. Some substantiation thereof obtains from the results of a series of fire tests of metal, concrete, and wood columns (9), in which column temperatures were obtained at 1½ ft. from the base protections and at two intermediate locations. While in many tests the temperatures at the outer locations were lower than over the central part of the height, the differences were in degree such that they could have been due in large part to differences in furnace temperatures.

For walls and floor slabs the cooling effect extends farther from the border as might be expected in that the construction receives heat from only one side. For most conditions, however, at 2 to 3 ft. from the border temperatures are indicated as differing little from those over the central portion that are almost fully free from any border effect. Even at 1½ to 2 ft., for some assumed values of thermal constants, the differences as computed were of the order that may obtain experimentally from incidental differences in specimens and test conditions. Limited experimental verification was obtained in a series of fire tests of clay structural tile walls (3) where otherwise comparable specimens were tested in sizes from 11 by 16 ft., to 4 by 4 ft. For the larger specimens measurements of surface temperatures were made at points not nearer than 2½ to 4 ft. from the border and for the smaller at 1 to 2 ft. While the determinations with the latter gave evidence of border effect, the temperature rise on the unexposed surface that determined the fire-endurance periods of the walls was in general obtained in shorter time than with nominally comparable larger specimens. This was indicated as attributable to a drier condition at the time of test from aging in a room that was generally at higher temperature and lower humidity than obtained for the larger specimens.

More information from tests and theory is required on the general subject before conclusions can be reached that cover an adequate range in material, design, and thickness of specimen. Experimentally, information can be obtained with temperature measurements at close intervals on one or more lines from the border to the central part of the specimen. For good application of theoretical methods, further determination of values of thermal constants are needed that are applicable to conditions obtaining in fire tests.

GENERAL COMMENTS

In fire tests it is not possible to control closely either the fire exposure or other conditions, such as distribution of load and restraint, that all have a bearing on results. However, the results are in as good general accord with theoretical relations as can be expected, considering these limitations. The relatively large size of specimen required according to standard specifications is advantageous in several respects in obtaining representative results. Supplementary valid information can be obtained with fire tests of smaller specimens if the stability of the specimen as a whole and its component parts has been established in tests with specimens of standard or larger size. In any case, the size should be such that temperatures over a representative portion of the specimen will not be appreciably affected by gradients near the border.

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[4] Acknowledgment is made to H. W. Woolley of the National Bureau of Standards for theoretical developments on which this discussion is in part based.

The mounting of the specimen and testing conditions should be representative as far as possible of fire exposure conditions for building members. In applying the load to be carried by walls and columns during test, it may be necessary to place self-adjusting blocks under one or both bearings, but during the fire test the condition of fixed ends should obtain. Some degree of continuity is representative for specimens of floor constructions that are normally built continuous over the supports. This can be obtained by including one or more beams or girders at other location than the margin. These, however, should not be depended on to induce a representative degree of restraint on other than light construction spanning between them. Heavier construction, such as 6 in. or thicker concrete slabs, require for the purpose contact at the bearings with a rigid restraining frame.

Established relations, such as that between fire-resistance periods and thickness, can be applied to advantage in limited interpolation and extension of information from fire tests, if performance in respect to stability under fire exposure and related properties has been determined in appropriate tests. Similar methods have been applied extensively and to advantage in related fields such as for the determination of the heat conductivity of building and other constructions. It is, however, not in general possible to compute fire-resistance values based on design and thickness and the thermal and other physical constants of the materials because of decided, and in part undetermined, changes in these latter with temperature and the heat transfer conditions incidental to fire exposure. The method is accordingly limited, in arriving at results, to comparisons of thickness or other applicable dimension of the cross-section, of constructions for which fire-resistance tests have been made with one or more values of the dimension.

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DISCUSSION

Mr. A. J. Steiner.[1]—Mr. Ingberg is to be complimented on a complete analysis and conclusions. The theory set forth seems to be primarily based on masonry or structures of uniform cross-sections. It is gratifying to obtain statements from a source so well qualified as Mr. Ingberg, especially as expressed in the general comments of his paper.

If I understand the paper correctly, it states that supplementary information can be obtained from fire tests of smaller specimens if the stability of the structure and its component parts have been established by standard or large scale samples as called for by A.S.T.M. Methods C 119.

It is unfortunate that those with considerably less experience than Mr. Ingberg are ready to draw conclusions from small scale tests of structures on which standard size tests have not been conducted.

I wonder if Mr. Ingberg agrees with our experience at Underwriters' Laboratory that the theory set forth is not necessarily adaptable to non-uniform structures comprised of various materials assembled to produce desirable physical performances under normal use conditions, but when exposed to fire, will develop non-uniform failure characteristics because of mechanical action caused by local stresses produced by uneven heating of parts of the structure and, therefore, the theory set forth has only a limited use.

Mr. S. H. Ingberg (*author's closure*).—I do not think Mr. Steiner's question can be answered much further than the general conclusions given in the paper with which he apparently agrees as limited to structures that are more or less uniform throughout. That is, they do not have details that may cause local failures or complications.

I am not entirely certain that I understand everything that is implied therein. I think the full-scale test should be made at least to the extent that information is obtained on the significance of these local failures, if they are due to the expansion or other characteristics of a specimen of standard size, and that they would not be as serious in tests made with the specimen of smaller size. I believe that may be the gist of the argument, and to that extent, I am quite in agreement with Mr. Steiner.

In a more general sense the paper can be taken as an endeavor to relate the results of one test with those of others, based on size of specimen and other applicable conditions. The availability of means for so doing is fundamental to the development of any engineering art or science. Isolated results have but limited value for the purpose. Only as correlated in a body of related data with the aid of applicable general relations can they contribute in significant degree to the general objectives of the field.

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A METHOD FOR EVALUATING THE SURFACE AND VOLUME RESISTANCE CHARACTERISTICS OF SOLID DIELECTRIC MATERIALS[1]

By William G. Amey[2] and Ferdinand Hamburger, Jr.[3]

Synopsis

Any attempt to measure the surface electrical properties of a solid dielectric gives rise to a result differing from the true value because of the effect of the shunt path through the volume of material between measurement electrodes. For a given specimen and electrode configuration, the error tends to be excessive whenever the ratio of surface resistivity to volume resistivity becomes high. Under such circumstances, the true surface properties can be obtained only by evaluation of the effect of the shunting volume path and subsequent correction of the nominal surface measurements.

Similarly, any attempt to measure the volume electrical properties tends to be compromised by the effects of stray currents over the surface paths between measurement electrodes. A three-electrode disk specimen, one electrode of which serves as a guard, has long been employed in the determination of volume resistivity for this reason.

The work reported herein was undertaken in an effort to determine the relative specimen and electrode dimensions which would allow use of the three-electrode disk for reasonably accurate evaluation of surface resistivity as well as volume resistivity. Analysis, substantiated by experiment, indicates that not only is the three-electrode disk necessary and satisfactory for volume resistivity measurements, but, also, it is the best arrangement for surface resistivity measurements. This specimen and electrode arrangement is, therefore, ideally suited to both types of measurement on the same specimen.

The analysis is outlined, and formulae given, by means of which suitable dimensions can be so chosen that correction of the observed data is unnecessary for wide ranges of material properties. In the rare cases where such corrections might be necessary, the fact is made apparent, and corrections can be effected, directly from the observed values.

High "insulation resistance" or opposition to the passage of electricity is the primary characteristic of all solid dielectric materials. Such insulation resistance is determined, however, not only by the opposition of the material to current flow through its volume, but also by the opposition to current flow across its surface. These two fundamental properties usually are discussed in terms of either the "volume" and "surface" resistivities of a material, or the "volume" and "surface" resistance of a particular specimen.

Both the volume and surface resistivities, while generally high, are of finite magnitude. Consequently, insulation resistance of any specimen involves the simultaneous effects of both surface and volume characteristics. In many cases, measurement of the aggregate effect (insulation resistance) for bushings, terminal strips, binding posts, etc., is sufficient. For quality control and for certain specific applications, however, separation of the surface and volume effects frequently is required. Special measurement procedures and specimen arrangements are necessary for this purpose.

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[1] Based on a dissertation submitted by W. G. Amey to the Advisory Board of the School of Engineering, The Johns Hopkins University, in conformity with the requirements for the degree of Doctor of Engineering.

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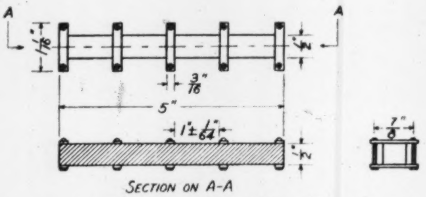

FIG. 1.—Application of Strip Electrodes to Flat, Solid Specimens.

Techniques for the separation of volume and surface effects are dependent primarily on specimen and electrode geometry tending to emphasize that characteristic under study. Most of the specimen and electrode arrangements reported to date are suitable for evaluation of either the volume or the surface characteristic, but not both. For example, A.S.T.M. Methods D 48 – 46 T[4] recommends the arrangement of Fig. 1 for the measurement of insulation resistance when surface phenomena are to be emphasized. The three-electrode arrangement of Fig. 2, however, is recommended when volume phenomena are to be observed. In many instances, adequate separation of surface effects is impossible with the specimen arrangements usually employed.

Herein are reported the results of efforts to obtain a specimen and electrode arrangement allowing accurate evaluation of both surface and volume properties for wide ranges of conditioning procedures, ambient temperature and humidity, and material properties. Some of the techniques described are recommended in a revision of A.S.T.M. Methods D 257 – 46[5] now in preparation for letter ballot of A.S.T.M. Committee D-9. Discussion of that proposed revision indicated the necessity for a step-by-step exposition of the problem and its solution. Since such an exposition cannot feasibly be included in A.S.T.M. Methods D 257, this paper has been prepared in the hope that it would supplement the proposed revision.

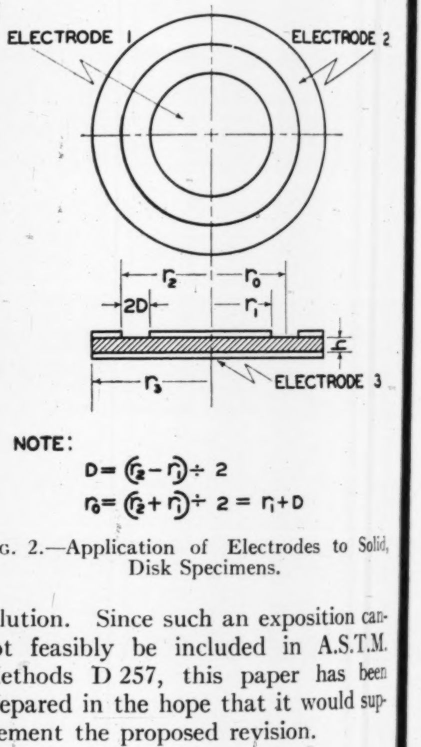

FIG. 2.—Application of Electrodes to Solid, Disk Specimens.

ELECTRODE CONFIGURATION EFFECTS ON SURFACE MEASUREMENTS

Selection of a general configuration of specimen and electrodes was made only after due consideration of the possible effects on the measurements.

Every measurement of surface resistance requires at least two electrodes common to the same surface of the specimen and held at different potentials. The resistance may be measured (according to A.S.T.M. Methods D 257 – 46)[5] either indirectly in terms of the ratio of the electrode potential difference to the current between the electrodes, or directly by comparison with a known resistance in a Wheatstone bridge. In either case, the fundamental question is: to what extent does the total measured resistance between surface electrodes differ from the actual resistance of the surface film?

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[4] Tentative Methods of Testing Molded Materials Used for Electrical Insulation (D 48 – 46 T), 1946 Book of A.S.T.M. Standards, Part III-B, p. 527.

[5] Standard Methods of Test for Insulation Resistance of Electrical Insulating Materials (D 257 – 46), 1946 Book of A.S.T.M. Standards, Part III-B, p. 135.

In terms of current, the fundamental concern is with those portions of the total measured current passing between surface electrodes by way of extraneous surface or volume paths rather than over the surface path being studied. The lower the ratio of extraneous current to main surface current, the lower the error.

In terms of resistance, the concern is with the amount by which the actual resistance of the main surface path is shunted by the resistances of the extraneous paths in the process of measurement. The lower the ratio of main surface path resistance to effective shunting resistance, the lower the error.

The ideal circumstances are those in which the effects of all extraneous paths are negligible. In the next best alternative, extraneous surface path effects are either zero or negligible, while the volume path effect, if not negligible, is calculable and readily taken into account.

The arrangement of Fig. 1 is based on the efforts of Curtis (**1**),[6] but its dimensions are not consistent with the fundamental concepts he advanced. With this specimen, two surfaces of different character (one molded, the other machined) usually are involved. The differing resistivities of the two types of surface may introduce an uncertainty which is even more confusing than that caused by the volume path.

Curtis (**1**, p. 366) attempted to obtain satisfactory conditions with an arrangement similar to that of Fig. 1 by more suitable dimensioning of the specimen and electrodes. More recently, Field (**2**) has employed a two-electrode arrangement similar to that of Curtis in studies of the surface resistivities of many of the present-day dielectric materials. Exhaustive discussion of these excellent works is impossible here, however, and a few brief comments must suffice. Both investigators satisfactorily reduced extraneous surface leakage effects by suitable proportioning of the specimen dimensions and the surface electrode separation. Curtis found, however, that the volume path effects often were not negligible (**1**, p. 411–414). Field (**2**, p. 6–7) avoided volume effects by making measurements before the ambient humid atmosphere had time to reduce the volume resistivity. This technique proved reasonably successful with the exceptions of certain materials which absorbed water so rapidly that the equilibrium surface resistance value was completely obscured. In general, such a procedure is not applicable to long-time humidity exposure studies or to materials possessing inherently low volume resistivity. It should be noted, however, that the techniques of Curtis and Field are quite useful and are entirely adequate for surface resistance studies of many of the dielectrics in use today.

From the above considerations, an arrangement like that of Fig. 2 appeared to be the only one likely to be suitable for measurements of both volume and surface resistivity, the guard electrode technique being virtually mandatory for volume resistivity measurements free of surface effect errors. It was believed that, by properly proportioning the specimen and electrode dimensions, surface resistivity could be measured without undue errors from volume paths of relatively low resistivity. This view was substantiated by subsequent analysis and experiment as will be shown.

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[6] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1091.

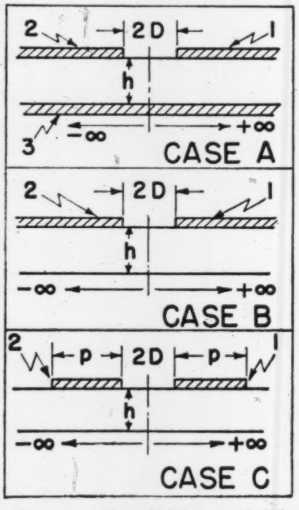

FIG. 3.—Cross-sectional Views of Theoretical Electrodes Arrangements. (*Case A*: Three electrodes. *Case B*: Two semi-infinite electrodes. *Case C*: Two electrodes of finite width, *P*.)

ELECTRODE CONFIGURATION ANALYSES

Prior to selection of suitable dimensions for the arrangement of Fig. 2, it was first necessary to evaluate the effect of the volume current path. In order to simplify the mathematical analysis, it was assumed that the dielectric material was homogeneous and isotropic, and that its properties were independent of the potential gradient. These assumptions were deemed sufficiently valid for the accuracies involved in such resistivity measurements. At any rate, measurements of an actual material can be used to indicate departures from the ideal only if the theoretical ideal relations are known.

Even with the above assumptions, direct analysis of the disk arrangement was found to be exceedingly difficult because of the mixed boundary conditions across the disk face containing the surface gap. Further, it appeared unlikely that the result could be expressed in a form convenient for calculation.

Frequently, when the three-dimensional problem involves axial symmetry, valuable information can be obtained by studies of a suitable two-dimensional configuration from which the original arrangement can be derived by rotation about an axis. Such was the situation here. For purposes of comparison, two additional electrode arrangements also were investigated. Cross-sectional views of the arrangements studied are shown in Fig. 3.

Case A involves two electrodes (1 and 2) of semi-infinite extent, common to the same surface of a dielectric specimen of finite thickness, *h*, and separated by a finite distance, *2D*, at the center line of the specimen; a third electrode (3) is infinite in extent, covering the entire opposite face. One is concerned in case A with the volume current which flows directly between electrodes 1 and 2, *when electrodes 1 and 3 are maintained at the same potential*, the latter being different from that of electrode 2.

Case B involves a configuration identical with that of case A, except that electrode 3 is absent.

Case C is virtually the same as case B, electrodes 1 and 2 being of equal and finite width, *p*.

Before proceeding to a discussion of these three electrode systems, a few quantities used in the analysis are defined as follows:

l = length of the electrodes taken perpendicular to the cross-sections shown,
D = half the gap width between electrodes 1 and 2, measured in the same units as l,
h = specimen thickness in the same units as l,

τ = volume resistivity expressed in terms of the same unit used for l, h and D,

σ = resistivity of the surface film in ohms per unit square of surface,

V_{12} = potential difference between electrodes 1 and 2,

I_{12} = volume current between electrodes 1 and 2,

Is = main surface current between the same pair of electrodes,

$R_{12} = V_{12} \div I_{12}$ = resistance of the direct volume path between electrodes 1 and 2, and

$Rs = V_{12} \div Is$ = resistance of the main surface path between the same pair of electrodes.

Now, if D and h be considered as the independent variables, it may be shown (3) that:

$$\frac{I_{12}}{Is} = \frac{Rs}{R_{12}} = \frac{\sigma}{\tau} hF(D/h), \qquad \text{(1)}$$

the function $F(D/h)$ taking a different form for each of the cases illustrated in Fig. 3.

From Eq. 1, it is evident that the error due to volume current increases with the ratio σ/τ. This ratio is a property of the material under observation. It is not subject to control except in the special and limited technique employed by Field as previously noted. It is further evident that the error can be reduced by the simple expedient of reducing the specimen thickness, h. Field employed this device, also. In many cases, however, the experimenter is faced with the problem of making measurements on specimens whose thickness is fixed.

The function $F(D/h)$, on the other hand, is determined by the electrode geometry and *is* subject to control within broad limits, the most satisfactory electrode system being that for which this function is smallest. For purpose of comparison, Fig. 4 shows plots of $F(D/h)$ for the three different electrode systems under consideration.

The lower curve of Fig. 4 corresponds to case A, and the middle one to case C when the electrode width p is one-tenth the specimen thickness. A single curve is sufficient to represent case C when the ratio p/h is equal to, or greater than, unity. This is the upper curve of Fig. 4, and includes case B for which p/h is infinite. For convenience only, Fig. 4 is plotted with 0.1 and 2.0 as the lower and upper limits of D/h. This shows the important characteristics for the several configurations and provides a satisfactory working range.

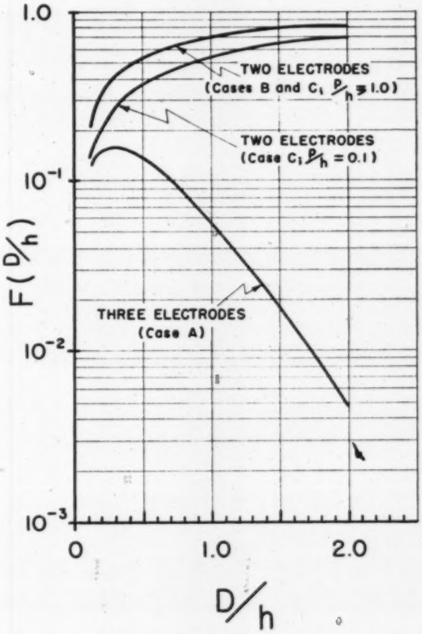

FIG. 4.—Effect of Electrode Geometry on Ratio of Volume to Surface Current Indicated by $F(D/h)$.

In conjunction with Eq. 1, Fig. 4 graphically demonstrates that:

1. When only two electrodes are employed, increasing the electrode separation with respect to the specimen thickness is detrimental, rather than helpful, in reducing the effect of the volume path. (While not shown, $F(D/h)$ approaches unity as D/h grows larger.)

2. When only two electrodes are employed, drastic reductions of electrode size with respect to specimen thickness are of little avail in reducing the effect of volume path.

3. When the three-electrode technique is employed, increases in the ratio D/h beyond the value 0.3 are tremendously helpful in reducing the effect of volume path. (This is independent of electrode width within broad limits. More complete analysis (**3**, Appendix A, pp. 17–18) shows that the width of electrodes 1 and 2 need only be equal to, or greater than, twice the specimen thickness.)

4. In all three cases, reduction of specimen thickness results in reduction of the volume path effect for all values of D/h. The three-electrode arrangement, however, is always superior in its effectiveness.

If D/h is unity, the three-electrode technique is approximately ten times more effective than the two-electrode method in achieving the desired result. If D/h equals 2, the relative effectiveness is 150 to 1.

THREE-ELECTRODE DISK

As previously indicated, analysis of case A of Fig. 3 leads to an approximate, but sufficiently accurate, analysis of the disk arrangement of Fig. 2 (**3**, Appendix B, p. 39). In order for the analysis to hold, certain conditions must be imposed on the electrode radii, namely,

$$r_1 \div h \overline{>} 2 \ldots\ldots\ldots (2)$$

$$(r_3 - r_2) \div h \overline{>} 2 \ldots\ldots\ldots (3)$$

$$D \div r_0 \overline{<} 1/2 \ldots\ldots (4)$$

Subject to the above limitations, the surface resistance and the three inter-electrode volume resistances of the disk are given by the following Eqs. 5, 6, 8, and 10:*

$$R_{ds} = \frac{\sigma}{2\pi} \, ln \frac{r_2}{r_1} = \frac{\sigma}{\pi} \frac{D}{r_0} \left[1 + \tfrac{1}{3} \left(\frac{D}{r_0} \right)^2 + \tfrac{1}{5} \left(\frac{D}{r_0} \right)^4 + \cdots \right] \ldots (5)$$

where R_{ds} = total surface resistance between electrodes 1 and 2.

$$R_{d12} = \frac{\tau}{S_{d12}} \ldots\ldots\ldots\ldots (6)$$

where:

R_{d12} = total volume resistance between electrodes 1 and 2,

S_{d12} = disk shape factor for the volume path between electrodes 1 and 2.

$$S_{d12} \approxeq r_0 \left[2 \, ln \tanh \left(\frac{\pi}{2} \frac{D}{h} \right) \right] \ldots\ldots (7)$$

$$R_{d13} = \frac{h\tau}{\pi[r_0 - \delta]^2} \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

where:

R_{d13} = total volume resistance between electrodes 1 and 3,

δ = fringing constant,

$$\delta \approxeq h \left[\frac{2}{\pi} \, ln \cosh \left(\frac{\pi D}{2h} \right) \right] \ldots\ldots (9)$$

$$R_{d23} = \frac{h\tau}{\pi[r_3^2 - (r_0 + \delta)^2]} \ldots\ldots (10)$$

where:

R_{d23} = total volume resistance between electrodes 2 and 3,

δ = fringing constant as above.

If Eq. 5 be divided by Eq. 6, the result

$$\frac{R_{ds}}{R_{d12}} = \frac{\sigma}{\tau} \cdot D \cdot \left[\frac{2}{\pi} \, ln \tanh \left(\frac{\pi}{2} \frac{D}{h} \right) \right] \left[1 + \frac{1}{3} \left(\frac{D}{r_0} \right)^2 + \frac{1}{5} \left(\frac{D}{r_0} \right)^4 + \ldots\ldots \right]$$

Multiplying and dividing by the specimen thickness h, this expression becomes

$$\frac{R_{ds}}{R_{d12}} = \frac{\sigma}{\tau} \cdot h \cdot \left[\frac{D}{h} \frac{2}{\pi} \, ln \tanh \left(\frac{\pi}{2} \frac{D}{h} \right) \right] \left[1 + \frac{1}{3} \left(\frac{D}{r_0} \right)^2 + \frac{1}{5} \left(\frac{D}{r_0} \right)^4 + \ldots\ldots \right]$$

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*ln designates logarithm to the base $\epsilon = 2.718\cdots$.

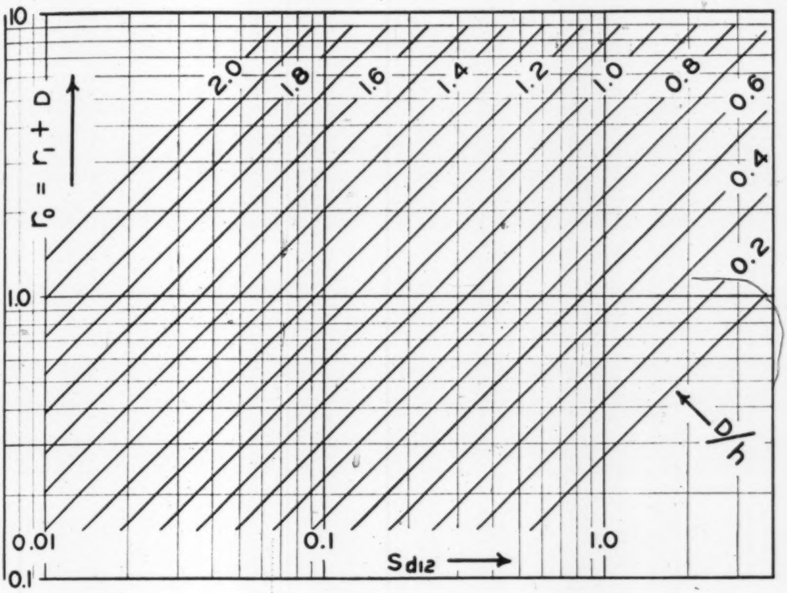

FIG. 5.—Plot of Disk Shape Factor, S_{d12}, for Volume Path between Surface Electrodes 1 and 2.

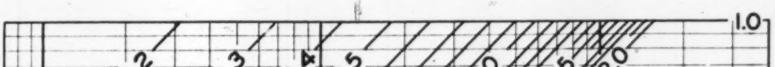

FIG. 6.—Plot of Fringing Constant, δ.

The first bracketed terms constitute $F(D/h)$ used in Eq. 1 and plotted in Fig. 4. The second bracket includes the correction factor relating to curved electrode edges of the disk as compared with the straight electrode edges of the two-dimensional analysis. In practice, this correction is essentially negligible, and

$$\frac{R_{ds}}{R_{12}} \cong \frac{\sigma}{\tau} \cdot h \cdot F(D/h). \quad \ldots\ldots\ldots(11)$$

Equation 11 indicates that the effectiveness of the three-electrode disk arrangement also can be determined from Fig. 4 and compared with two-electrode arrangements on the same basis.

Equations 2, 3, and 4 impose certain conditions on the specimen and electrode dimensions of the general arrangement shown in Fig. 2. When these conditions are satisfied, the relations in Eqs. 5 to 10 inclusive allow the computation of any of the pertinent factors associated with surface and volume resistivity measurements on such a specimen.

With the exceptions of Eqs. 7 and 9, evaluation of the various resistances offers no difficulty. Since Eqs. 7 and 9 involve natural logarithms of hyperbolic functions, and since these are not given explicitly in most mathematical tables, Figs. 5 and 6 are provided as convenient aids in the evaluation of S_{d12} and δ respectively. It should be observed that no dimensional units are indicated, S_{d12} being in the same units as r_0, and δ in the same units as h. In this manner, Figs. 5 and 6 lend themselves to convenient calculation no matter what the length unit might be.

Experimental verification of the above relations was obtained through resistance measurements on disks of the carbon-binder mixtures used in radio-frequency resistors (**3**, pp. 25–36). These disks, having an average volume resistivity of 10^5 ohm cm., were supplied by the manufacturer with sprayed copper electrodes on the circular faces. In order to form electrodes 1 and 2, it was necessary only to face-off a ring of the sprayed copper. Thus it was possible to check the validity of the above relations for a wide range of electrode dimensions.

Unfortunately, these tests cannot be treated in detail in this paper; a simple statement of results must suffice. While Eqs. 7, 8, and 10 are not exact, both analysis and experiment have shown them to be more than satisfactory for the purposes intended. The error in Eqs. 8 and 10 appears to be appreciably less than one per cent; that of Eq. 7 varies from 1 to 10 per cent, depending on the electrode dimensions. This latter discrepancy is of no consequence. In the case of surface resistivity measurements, one is concerned only that the resistance of the undesirable volume path, R_{d12}, should be of the high order of magnitude predicted by Eqs. 6 and 7. An error of as much as 50 or 100 per cent for R_{d12} would be of little significance in a properly proportioned specimen.

RECOMMENDED SPECIMEN AND ELECTRODE DIMENSIONS

The relations in the preceding section are intended to allow application of the three-electrode disk technique to specimens of many sizes. It appears in order, however, to recommend standard arrangements for general-purpose work.

While there are many bases on which the specimen and electrode dimensions might be selected, certain practical considerations must influence the final decision. The most important consideration involves the usual forms in which specimen materials are available; on this basis alone, a decision can be made.

In the past, disks of either 2 or 4-in. diameter have been used in dielectric testing. Indeed A.S.T.M. Method D 48 – 46 T specifies a disk $\frac{1}{8}$ in. thick and 4 in. in diameter for volume resistivity measurements on molded electrical insulating materials. Most material manufacturers, and many testing laboratories, are equipped to mold either 2-in. or 4-in. disks in thicknesses ranging from $\frac{1}{16}$ in. to $\frac{1}{2}$ in. At the same time, materials other than the molded ones offer little difficulty. These normally are available in a variety of thicknesses and can be cut to the desired diameter. For such reasons, it appears that the A.S.T.M. specimen noted above should be entirely suitable; a specimen $\frac{1}{8}$ in. thick and 2 in. in diameter being a less desirable alternative because of the higher resistances which are thus involved. With reference to Fig. 2, this amounts to a decision that $h = \frac{1}{8}$ in. and $r_3 = 2$ in. for the standard specimen and $h = \frac{1}{8}$ in. and $r_3 = 1$ in. for the alternate. Further, reference to Eq. 3 indicates that r_2 should then be 1.75 and 0.75 in. respectively.

For given values of σ and τ, both r_0 and r_1 should be as large as possible to bring the measured surface and volume resistances within the range of available measurement apparatus. On the other hand, since r_2 is fixed by the specimen size, the larger r_1 the smaller the surface gap and the greater the adverse effect of volume current on surface measurements. This issue can be settled, fortunately, by reference to Fig. 4 and Eq. 11.

If $D/h = 1.0$, $F(D/h) = 0.056$ for the three-electrode case. Since $h = \frac{1}{8}$ in.,

$$\frac{R_{ds}}{R_{d12}} = 0.007 \frac{\sigma}{\tau} \quad \dots\dots\dots\dots (12)$$

according to Eq. 11. Under these circumstances, the error due to neglecting the volume path effect would not exceed 0.7 per cent, even in the rare case where σ and τ were equal in magnitude. Consequently, the value $D/h = 1.0$ seems to provide a fair compromise, and r_1 becomes 1.500 in. for the standard disk and 0.500 in. for the alternate.

Table I lists the dimensions of the proposed standard and alternative arrangements. Also listed are all the other pertinent factors as computed from the previously cited analyses.

For either of the two arrangements considered in Table I, items 18, 19, and 20 are the most important and significant. Item 18 provides a relatively simple and quick means for evaluating R_{d12} from the measured value of R_{d13}. From this and the observed value of R_{ds}, one can quickly decide whether or not R_{d12} is likely to cause appreciable error.

Items 19 and 20, Table I, provide a simple means for computing the volume and surface resistivities from the measured values of R_{d13} and R_{ds} respectively. Further, these two items indicate the maximum resistivities that may be measured with the given specimen types and with a given maximum measurable resistance. For example, if the available equipment permits measurement of 10^{12} ohms, item 19 indicates that the maximum volume resistivity measurable with the standard disk is 60.7 times the given resistance sensitivity, that is, 60.7×10^{12} ohm in. (1.54×10^{14} ohm cm.). The limit would be 7.66×10^{12} (about 1.95×10^{13} ohm cm.) for the alternate type.

RESULTS WITH DIELECTRIC SPECIMENS

The proposed technique was applied to measurements of actual dielectric materials with gratifying results. The purpose here was not to establish a table of dielectric properties, but rather to show that the proposed technique allows the direct measurement of surface resistance for extreme ranges of volume resistivity.

The selection of dielectric materials was not difficult; there was no choice, laminates being the only materials readily available at the time. This, however, was not considered particularly unfortunate for the purpose at hand. It was necessary that measurements be made over a wide range of values of σ/τ. It appeared that this could be accomplished simply by exposure of the specimens to high ambient humidities, resistance measurements being made at various exposure times. Most laminates are admirably suited to this somewhat peculiar requirement that volume resistivity should change markedly with humidity exposure. Further, if the measurement technique proved applicable to the laminates (which are inherently anisotropic), it should be applicable to all of the more uniform types of material.

TABLE I

Item	Pertinent Factors for Three-Electrode Disk Configuration	Symbol	Specimen Type		Reference
			Standard	Alternate	
1	Specimen thickness, in.	h	0.125	0.125	Fig. 2
2	Radius, outside, electrodes 2 and 3, in.	r_3	2.000	1.000	Fig. 2
3	Radius, inside, electrode 2, in.	r_2	1.750	0.750	Fig. 2
4	Radius, electrode 1, in.	r_1	1.500	0.500	Fig. 2
5	Surface gap, electrodes 1 and 2, in.	$2D$	0.250	0.250	Fig. 2
6	Radius, average, surface gap, in.	r_0	1.625	0.625	Fig. 2
7	Ratio, half gap to specimen thickness	D/h	1.000	1.000	Fig. 4
8	Ratio, half gap to average gap radius	D/r_0	1/13	1/5	Eq. 4
9	Fringing constant, in.	δ	0.073	0.073	Eq. 9 Fig. 6
10	Radius, effective, outside, electrodes 2 and 3, in.	r_3	2.000	1.000	Fig. 2
11	Radius, effective, inside, electrode 2, in.	$r_0 + \delta$	1.698	0.698	Eq. 10
12	Radius, effective, electrode 1, in.	$r_0 - \delta$	1.552	0.552	Eq. 8
13	Disk volume shape factor, electrodes 1 and 2, in.	S_{d12}	0.280	0.108	Eq. 7
14	Volume resistance, electrodes 1 and 2, ohms	R_{d12}	3.57τ	9.26τ	Eq. 6
15	Volume resistance, electrodes 1 and 3, ohms	R_{d13}	0.0165τ	0.131τ	Eq. 8
16	Volume resistance, electrodes 2 and 3, ohms	R_{d23}	0.0356τ	0.0775τ	Eq. 10
17	Surface resistance, electrodes 1 and 2, ohms	R_{ds}	0.0245σ	0.0645σ	Eq. 5
18	Ratio of volume resistances	R_{d12}/R_{d13}	216	70	....
19	Volume resistivity of unit cube, ohm-in.	τ	$60.7\ R_{d13}$	$7.66\ R_{d13}$	Eq. 8
20	Surface resistivity of surface square, ohms	σ	$40.8\ R_{ds}$	$15.5\ R_{ds}$	Eq. 5

Specimens of each material were prepared as follows:

1. Four standard size disks and four of the alternate size were cut from the same sheet of $\frac{1}{8}$-in. material.

2. The disks were wiped clean with soft tissue paper and kept clean thereafter.

3. Electrodes were applied to each of the disks in accordance with the dimensions indicated by Table I, items 1 to 10 inclusive. The electrodes consisted of duPont No. 4365 Silver Conducting Coating applied with a small camel's hair brush, the gap area between electrodes 1 and 2 being carefully masked. No details of the masking technique will be cited here since any arrangement giving clean, sharp electrode edges would have been equally satisfactory. (Such electrodes do not appreciably affect the absorption of moisture from ambient humid atmospheres (4).)

4. After application of electrodes, the specimens were placed in a 50 C. oven for 96 hr. in an effort to reduce them all to a uniformly dry condition.

At the end of the drying period, all eight specimens of a given material were mounted in individual specimen holders attached to the same brass cover-plate. The latter was then inverted and used to cover the top of a battery jar. The cover-plate was sealed to the top edges of the battery jar by means of wax, effectively enclosing all eight specimens in the same humid atmosphere produced by a saturated solution of potassium nitrate covering the bottom of the jar.

The various jars were stored in a constant temperature room at approximately 25 C. This resulted in a relative humidity of the order of 85 per cent inside the jars. The actual relative humidity was of little consequence for these tests, the important consideration being that all eight specimens should be subject to the same conditions for purposes of comparison.

Connections to each of the three electrodes of each specimen were brought out through the brass cover-plate by means of steatite feed-through bushings.

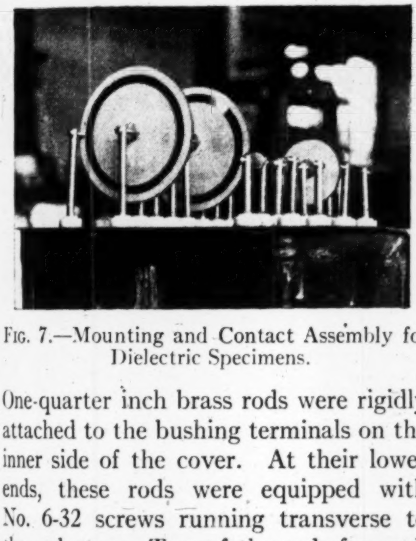

FIG. 7.—Mounting and Contact Assembly for Dielectric Specimens.

One-quarter inch brass rods were rigidly attached to the bushing terminals on the inner side of the cover. At their lower ends, these rods were equipped with No. 6-32 screws running transverse to the rod axes. Two of the rods for each specimen were provided with brass disks at the ends of their respective No. 6-32 screws. The specimen was placed between these two brass disks which were then screwed tightly against either side of the specimen at its center. In this manner, the specimen was rigidly supported from the cover-plate, and contact with electrodes 1 and 3 was achieved. Contact with electrode 2 was effected simply by bringing up the screw at the end of the third brass rod. The mounting and contact assembly is shown in Fig. 7.

Measurements were made at 100 v. in the following manner:

1. For measurement of the volume resistance, R_{d13}, electrode 1 was the guarded electrode, electrode 2 was the guard, and electrode 3 was the unguarded electrode.

2. The surface resistance, R_{ds}, was measured directly by having electrode 2 serve as the unguarded electrode, electrode 3 as the guard, and electrode 1 as the guarded electrode.

In all measurements, the brass cover plate was connected to whichever of the specimen electrodes was at that time serving as guard. In this manner, the insulation leakage currents of the steatite bushings were rendered ineffective. As the exposure period increased, the specimen resistances decreased, and some of the guard system resistances became very low. In each such case, simple corrections (based on measured values of guard system resistance) were made, the resistivities reported below corresponding to the corrected values of measured surface and volume resistance. (The effects of low guard system resistance are fully treated in the revision of A.S.T.M. D 257 now being prepared, rendering further discussion of this matter unnecessary here.)

It should be noted that the measured resistances were the stable values attained some five or more minutes after electrification of the specimen. Since the purpose of these tests was to compare data from the two specimen types, it was deemed advisable to thus avoid the variations which frequently result from trying to make measurements "on the run." The typical long-time absorption phenomena (resistance slowly rising to a final value) apparently were greatly obscured in these relatively wet specimens. Rather, the volume resistance quickly reached a maximum value and then dropped to a somewhat lower value which changed only slightly with further passage of time.

In the case of surface resistance the effects of time of electrification were somewhat different. For long periods between tests, the specimen electrodes were short-circuited. When surface resistance was first measured after such an extended period, its value increased slightly with time until stability was finally attained. Surface measurements repeated shortly thereafter exhibited no such characteristics, resulting always in the stable values attained in the first test of the given series. Field (2, p. 7; 5), as well as Thompson and Mathes (6), previously has reported similar effects.

TABLE II.—SURFACE AND VOLUME RESISTIVITIES—XXX LAMINATE 85 PER CENT RELATIVE HUMIDITY AT 25 C.

Exposure Period, days	Specimen Type	Surface Resistivity, σ, ohms	Volume Resistivity, τ, ohm in.	
			Effective Radius $= r_0 - \delta$	Effective Radius $= r_0$
1	4-in. disks	6.30×10^8	2.88×10^{11}	3.15×10^{11}
	2-in. disks	6.14×10^8	1.92×10^{11}	2.46×10^{11}
	Average	6.22×10^8	2.40×10^{11}	2.81×10^{11}
10	4-in. disks	3.30×10^7	1.39×10^9	1.52×10^9
	2-in. disks	3.05×10^7	1.20×10^9	1.54×10^9
	Average	3.18×10^7	1.30×10^9	1.53×10^9
17	4-in. disks	1.75×10^7	7.65×10^7	8.36×10^7
	2-in. disks	1.60×10^7	6.45×10^7	8.26×10^7
	Average	1.68×10^7	7.05×10^7	8.31×10^7
27	4-in. disks	1.02×10^7	1.34×10^7	1.47×10^7
	2-in. disks	0.94×10^7	1.07×10^7	1.37×10^7
	Average	0.98×10^7	1.21×10^7	1.42×10^7

It is impossible to present here all of the data thus obtained in comparing the two specimen types. An entirely representative set of results is shown, however, in Table II. The third column lists, for each of the several exposure periods, the average surface resistivity determined from measurements on the 4-in. diameter disks, that from the 2-in. disks, and finally, the average value from all specimens of the given material. It will be observed that the average surface resistivity for either type of specimen deviates from the average for all specimens by less than 5 per cent.

The last two columns of Table II list, in a similar manner, the volume resistivity computed from the volume resistance on two difference bases. The first of these entailed the use of Eq. 8 where the effective radius of electrode 1 appears as $(r_0 - \delta)$; the second set of volume resistivities was calculated on the assumption that the effective radius was r_0. Considering the usual variations in properties from specimen to specimen, even of the same material, the agreement of the volume resistivities from the two specimen types is remarkable on either basis of computation. It is believed, however, that the resistivities computed on the assumption of an effective electrode radius equal to r_0 probably are more nearly correct.

In this latter connection, it must be remembered that the electrode configuration analysis for the resistance between electrodes 1 and 3 assumed an isotropic medium. The relation in Eq. 8, thus obtained, was verified by the measurements on carbon disks which were relatively homogeneous and isotropic. The laminates, however, are anisotropic; resistivity parallel to the laminations being somewhat lower than that in the perpendicular direction. Fringing at the outer edge of electrode 1 probably was greater than normal, and the effective electrode radius thereby increased.

At any rate, the relatively wide divergence at the end of the first day, compared with the relatively close agreement after 10 days, indicates a more rapid absorption of moisture for the 2-in. disks than for the larger ones. This seems to be consistent with the previous findings of Kline (7) and his associates regarding the effect of specimen proportions on moisture absorption by plastics.

CONCLUSIONS

From the foregoing analysis and experimentation, conclusions may be drawn as follows:

1. With properly proportioned specimen and electrode dimensions, the three-electrode disk arrangement is well suited to direct evaluation of surface resistance and resistivity for wide ranges of ambient conditions and material properties.
2. With such proportioning this arrangement is also well suited to volume resistance and resistivity evaluations with the same specimen.
3. The recommended specimen and electrode dimensions (Table I) are satisfactory and convenient to use, allowing the evaluation of relatively high resistivities with measuring equipment of moderate range.
4. The major disadvantage of the method arises in connection with its application to laminates. It cannot readily be applied to evaluation of volume resistivity parallel to the laminations; and the anisotropy modifies the effective electrode radius used in computing resistivities perpendicular to the laminations.
5. All factors considered, however, the technique is superior to that described in A.S.T.M. Methods D 257 – 46 where none of the pertinent considerations are discussed.
6. The two-dimensional analysis resulting in Eq. 1 and Fig. 4 provides a means of evaluating the relative effectiveness of many possible electrode arrangements other than the disk system discussed herein.

Acknowledgments:

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(7) G. M. Kline, A. R. Martin, and W. A. Crouse, "Sorption of Water by Plastics," *Proceedings*, Am. Soc. Testing Mats., Vol. 40, pp. 1273–1282 (1940).

FLEXURE TESTING OF PLASTIC MATERIALS*

By J. W. Westwater[1]

Synopsis

Seven factors concerning flexural testing of plastics were subjected to theoretical and experimental investigation: The effects of radius of the loading edges, amount of beam overhang, excessive beam curvature, horizontal force components at the supports, choice of span-depth ratio, variability of material, and the relationship between flexure, tension, and compression. The work was restricted to rectangular beams, simply supported and loaded at the midspan. Two phenolic laminates were used to represent stiff plastics; cellulose acetate and vulcanized fiber were used as ductile materials. Tests were conducted on a hydraulic tester in a room at controlled conditions.

The results show that appreciable effects are caused by horizontal force components at the supports; by varying the radius of the loading edges; or by ignoring the variability of commercial materials. Effects due to varying the beam overhang or due to excessive beam curvature are shown to be negligible ordinarily. Application to one material of the flexure-tension-compression correlation outlined by Nadai indicates that nearly pure tensile and compressive stresses exist within bent beams of this material.

The rapid growth of the plastics industry has led to a wide application of these materials to an extent which is often out of proportion to the existing knowledge of their structure and physical properties. The present state of knowledge is indicated by the fact that, of the 80-odd tests formulated by the A.S.T.M. for various physical properties of plastics, about three fourths are tentative standards subject to considerable revision as data become available.

Because flexure tests are relatively easy to carry out and because structural materials in use are very often subjected to bending loads, the measurement of flexural strength (modulus of rupture) has become routine. It was the purpose of this study to investigate the flexural strength of several plastic materials with respect to some of the factors expected to be of importance. Emphasis was given to plastic laminates, for at present the laminates find more extensive structural application than do the homogeneous plastics. Future experimenters might do well to investigate materials that are more homogeneous. Such materials should be more ideal from the standpoint of mathematical treatment.

Review of Literature on Plastics in Flexure

Since the plastics industry is still young, the amount of recorded information concerning plastics in flexure is rather meager. Some variables which are of interest but which are not studied in this paper, have been investigated previously. They include temperature effects (**3, 4, 5, 8, 11, 12**),[2] continuous exposure to heat (**4, 7**), humidity (**4**), average molecular weight (**3**), outdoor weathering and simulated weathering (**6**), and speed of test (**19**).

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The effect of radius of loading edges, one of the subjects treated in the present investigation, is covered in the work of Nason which is presented in a review by Zinzow (**19**). It is stated that the radius of the loading edges has no effect on cellulose acetate or polystyrene as measured by maximum fiber stress, yield point, or stress distributions at the contacts. These conclusions are discussed subsequently in this paper.

The effect of span-depth ratio, also treated in this paper, is discussed in an excellent paper by Tucker (**16**). Tucker reasoned that an increase in the span should cause a reduction in the flexural strength because of an increase in the probability of some weak spot being subjected to a load sufficient to break it.

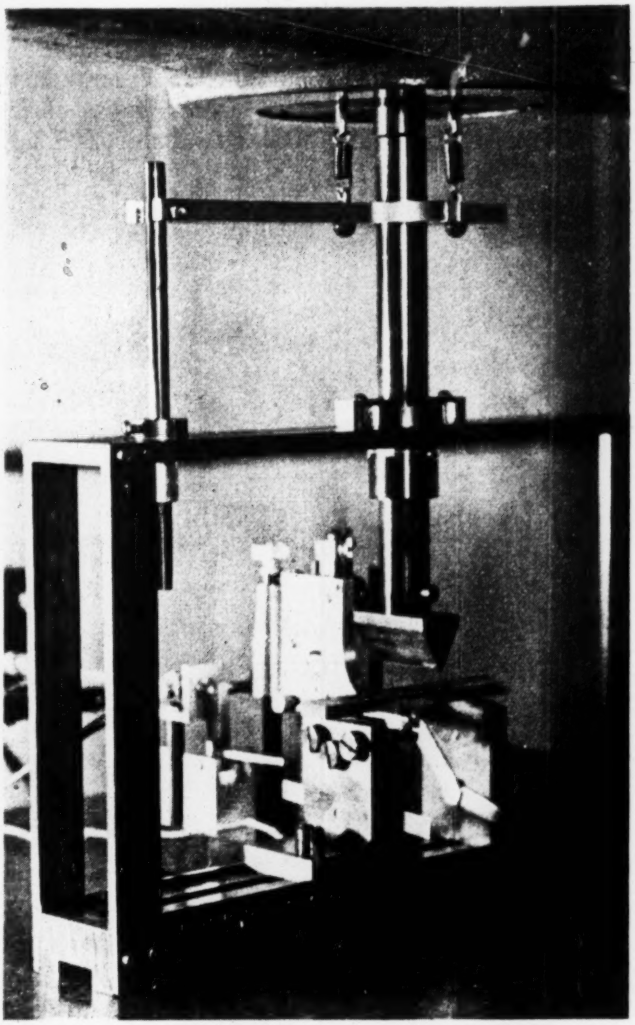

FIG. 1.—Apparatus Used for Flexure Tests.

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1117.

Data published later by Zinzow (19), Turner and Thomason (17), and Schoenborn, *et al* (14) verify the prediction. The theory of Tucker is based in part on probability considerations, as set forth by Weibull (18), and does not take into account such factors as horizontal forces at the supports.

The probability theory predicts that the value of the flexural strength should be independent of beam width. This prediction is likewise verified by the data of Schoenborn (14), as well as by some data given by Tucker for concrete. Tucker's theory states that the predominant effect of increasing beam width should be a decrease in the scatter of the data, the standard deviation being inversely proportional to the square root of the beam width. It is shown also that a centrally loaded beam should be stronger, theoretically, than a beam loaded at the one-third points, and the relationship between the two types of tests is developed by Tucker.

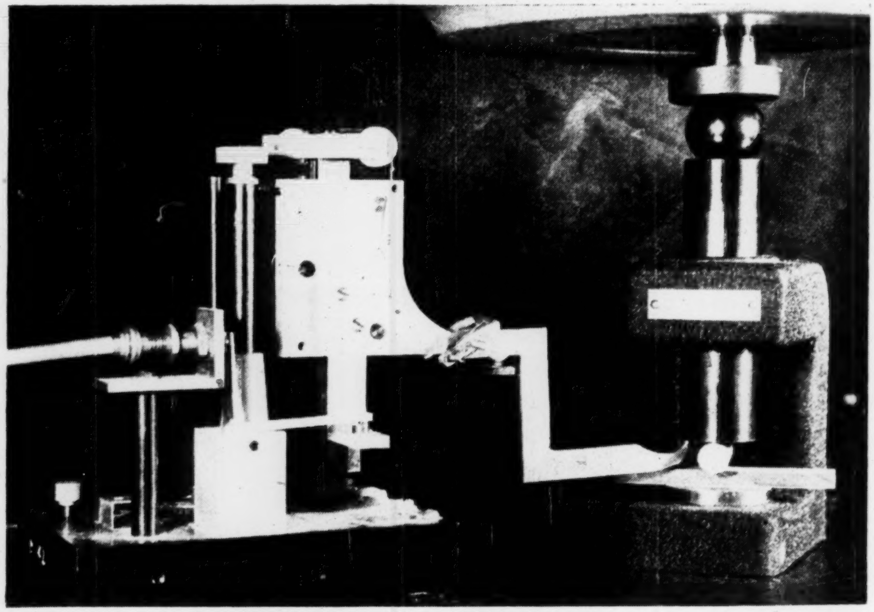

FIG. 2.—Compression Jig Used for Indentation Tests.

The natural variability of physical materials is emphasized by Tucker. A discussion of variability is also given by Turner and Thomason (17), and six observed distribution curves are presented. Variability is treated also in this paper.

APPARATUS

The tests were made in a hydraulic Baldwin - Southwark universal tester. The apparatus has three load scales (600, 6000, and 60,000 lb.), and the accuracy of the load indication is claimed by the manufacturer to be 0.5 per cent of the load or 0.1 per cent of the scale range, whichever is greater. An O. S. Peters, Selsyn-motor type deflectometer was used to measure deformation, and the load *versus* deformation curves were recorded automatically during the tests. Six magnifications of deformation were available, ranging from 5:1 to 200:1. The accuracy of the indicated deformation is about 0.0003 in. at best. A partial view of the deflectometer is shown in

Fig. 1. The load was applied directly to the beams by means of a plunger attached to the loading nose and sliding in a guide as shown in Fig. 1.

In order to study the effects of the radius of the contact edge, a special flexure test-rig, so constructed as to make possible an easy interchange of various supports and loading noses, was made available by the research laboratories of the Monsanto Chemical Co. This apparatus is partly visible in Fig. 7.

To carry out the study of indentation effects, a Sonntag compression jig was utilized as illustrated in Fig. 2. Three cylinders ($\frac{1}{2}$-in., $\frac{1}{4}$-in., and $\frac{1}{8}$-in. diameters) were used. Loads were applied and indicated by the universal testing machine. Deformation was measured by means of the deflectometer. The sensitive tip of the deflectometer was located beneath the piston of the jig initially (as is shown in Fig. 2), but for the later tests the deflectometer tip was located beneath the overhanging portion of the cylindrical indenter tool. The measurement obtained by the latter scheme consists of the true indentation plus sample compression and jig-base compression. The jig-base compression was computed to be extremely small; in fact, for a load of 5000 lb. the deformation was only 0.000087 in. The compression of the specimen may not be negligible, but it is not clear how this factor should be evaluated.

All test equipment was located in a constant-temperature, constant-humidity room controlled at 77± 1 F., 50± 2 per cent relative humidity. All tests were carried out at these conditions.

PROCEDURE

Conditioning:

The plastic materials were commercial grades and were obtained as full-size sheets directly from the manufacturers. The sheets were cut into test specimens at the University and were stored in the constant-temperature, constant-humidity room until used. Most pieces were conditioned for several months before testing, but in no case was the conditioning period after sectioning less than 20 days per inch of thickness. Because vulcanized fiber containing traces of moisture has an extremely low stiffness, the cut specimens of this material were oven-dried at 50 C. for 72 hr. and were then stored in calcium chloride desiccators at 77 F. until used.

Flexure Tests:

Where possible, the tests were made to conform with A.S.T.M. Tentative Methods of Test for Flexural Properties of Plastics (D 790 – 45 T).[3] Only rectangular beams, simply supported and loaded at the midspan, were used. The crosshead speeds corresponded with these specifications and the modulus of elasticity was computed in the manner described therein. Usually one variable only was allowed to change, and that was the particular factor under investigation. At least four duplicate flexure specimens were tested at each set of conditions.

Indentation Tests:

The specimens were rectangular slabs measuring 3 by $\frac{1}{2}$ in. by sheet thickness. Three tests were made on each slab, employing each of the three cylinders once. The indentations were made at the quarter points and at the midpoint of the test slab. The geometrical axes of the cylinders were oriented at right angles to the long dimensions of the slabs. The tests were conducted at a constant rate of loading, the value chosen being 3000 lb. per min. Five duplicate tests, using five different specimens, were made for each indenter.

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[3] 1946 Book of A.S.T.M. Standards, Part III-B, p. 858.

Tension and Compression Tests:

The tests to investigate the tension-compression-flexure correlation were made in accordance with A.S.T.M. Tentative Methods of Test for Compressive Strength of Plastics (D 695 – 44 T)[4] and for Tensile Properties of Plastics (D 638 – 46 T)[5] as nearly as possible. The deviations from these specifications were minor.

THEORETICAL CONSIDERATIONS

The flexure formula for "simple" beams, takes various forms when effects of various factors are brought into consideration. A simple beam is meant here to be one which is supported near the ends, which is loaded at the midspan, and which has a rectangular cross-section. The loading contacts are assumed to be cylindrical.

Common Flexure Formula:

The flexure formula in its most simple form is derived in many textbooks (13).

$$S_{\max} = \frac{3PL_0}{2bd^2}$$

All symbols are defined in the section on nomenclature.

The following assumptions are utilized in the derivation:

1. The proportional limit is not exceeded.
2. Modulus of elasticity in tension is the same as in compression.
3. The span does not change during a test.
4. No horizontal forces develop at the supports.

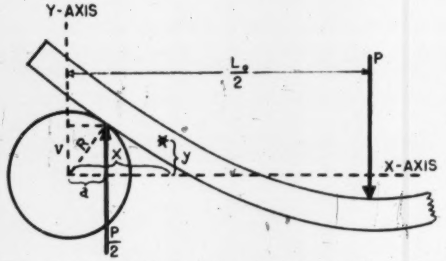

FIG. 3.—Span Shortening during Bending Test.

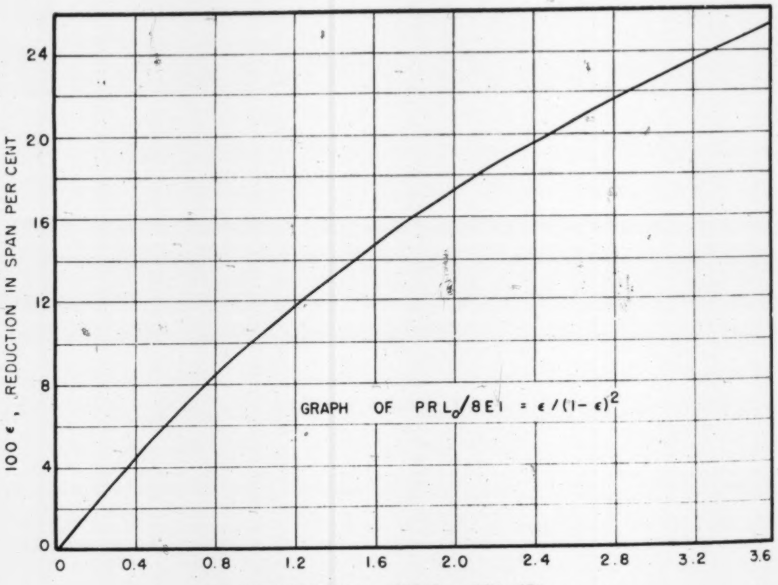

FIG. 4.—Theoretical Change in Span for Simple Beams under Load.

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[4] 1946 Book of A.S.T.M. Standards, Part III-B, p. 824.

[5] *Ibid*, p. 899.

5. No stress concentrations develop at the contacts

6. The slope of the neutral axis is small at all points compared to unity.

7. The strain of any "fiber" is proportional to its distance from the neutral axis.

8. Shearing stresses are negligible.

9. The loads are in one plane and are perpendicular to the neutral surface.

10. The beam is narrow.

It is desirable to derive a flexure formula which does not involve any of the above assumptions. This is a very difficult problem, but by considering some of the factors one at a time it is possible to demonstrate their effects as shown below.

Correction for Span Shortening:

A significant change in span can occur during a test only if the radii of curvature of the end supports amount to a reasonable fraction of the span. In no case can the span reduction exceed the sum of the radii of the two supports. The amount of span reduction is a function of the support radii, the original span, the specimen thickness and width, the modulus of elasticity of the specimen, and the load. For stresses within the proportional limit, the change may be predicted mathematically.

Considering Fig. 3, the original half-span $L_0/2$, is seen to be decreased by the amount, a, due to the rolling or slipping of the beam on its end supports. The point (x, y) on the neutral axis of the beam fulfills the condition:

$$y''EI = M_x \ldots\ldots\ldots (1)$$

All the assumptions enumerated, except the third, are implied. In this case, $M_x = P(x\text{-}a)/2$. It is realized that in actuality, the expression cannot hold strictly, for a reduction in span must give rise to horizontal reactions. This factor is considered in the following section. Integrating the equation once and substitution of the conditions, $y' = 0$ at $x = L_0/2$ and $y' = -\frac{a}{v}$ at $x = a$, gives the expression:

$$\frac{P(L_0 - 2a)^2}{16EI} = \frac{a}{\sqrt{R^2 - a^2}} \text{ (Exact)}. \ (2)$$

By use of Eq. 2, one may compute the amount by which the span decreases, $2a$, for a given set of conditions. A trial and error procedure is required for this purpose. However, it is frequently convenient to assume a^2 small compared to R^2, and this leads to a somewhat simpler expression. The error introduced by this assumption amounts to only 3 per cent for a beam forming an angle of 14 deg. with the horizontal at the supports. That is, the computed span change, $2a$, will be off 3 per cent; the computed span will not be in error this much. Applying the assumption, $R^2 >> a^2$, leads to:

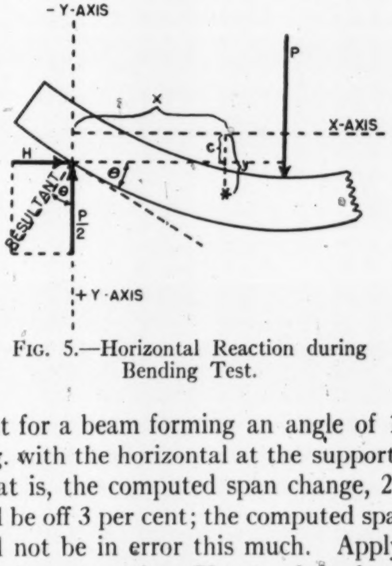

FIG. 5.—Horizontal Reaction during Bending Test.

$$\frac{\alpha}{8} = \frac{\epsilon}{(1 - \epsilon)^2} \quad \text{(Approximate)} \ldots (3)$$

where:

$$\alpha = \frac{PRL_0}{EI}, \quad \text{dimensionless}$$

$$\epsilon = \frac{2a}{L_0}, \quad \text{fractional reduction of span}$$

Eq. 3, the approximate form, may be graphed conveniently as shown in Fig. 4.

Correction for Horizontal Thrust:

As a simple beam is pushed down between its end supports, the beam exerts an outward thrust against the supports. If frictional forces develop against the supports, they have additional inward components. Results obtained to date, however, indicate that the frictional components are negligible for the few sets of conditions studied. A mathematical evaluation of the effects of horizontal thrust follows. All the enumerated assumptions except the fourth are implied in the derivation.

Referring to Fig. 5, the maximum unit stress, which can arise due to the bending caused by P and the bending and compression caused by the horizontal force, H, may be expressed as:

$$S_{\max} = \frac{M_{\max} c}{I} \pm \frac{H}{bd} \quad \ldots\ldots (4)$$

or

$$S_{\max} = \frac{3PL_0}{2bd^2} + [6\Delta - 3d \pm d]\frac{H}{bd^2} \quad \ldots (5)$$

The maximum tensile unit stress is found by using the negative sign on the last term; the maximum compressive unit stress is found by using the positive sign.

During ordinary flexure tests H is not measured, so an analytical method of arriving at its value is of interest. Considering the point (x,y) on the neutral axis of the beam shown in Fig. 5, $-y'' EI = M_x$. In this case $M_x = Px/2 + H(y\text{-}c)$. Note that H may either increase or decrease the bending, depending on whether y is greater than c or less than c. Substituting and letting $k^2 = H/(EI)$:

$$y'' + k^2 y = -Px/(2EI) + k^2 c \quad \ldots (6)$$

By integrating and using the conditions $y = 0$ at $x = 0$ and $y' = 0$ at $x = L_0/2$, one obtains the solutions:

$$y = -c\cos kx + \frac{P \sin kx}{2Hk\cos\frac{kL_0}{2}} - c(\sin kx)\left(\tan\frac{kL_0}{2}\right) - \frac{Px}{2H} + c \quad \ldots (7)$$

and

$$y' = ck\sin kx + \frac{P\cos kx}{2H\cos\frac{kL_0}{2}} - ck(\cos kx)\left(\tan\frac{kL_0}{2}\right) - \frac{P}{2H} \quad \ldots (8)$$

These two equations are not particularly useful as they stand, but if the horizontal force contains no component due to friction, then the resultant of H and the vertical reaction must be perpendicular to the neutral axis of the beam, as shown in the sketch. If friction is appreciable, the resultant will not be at the angle θ. But assuming negligible friction, $y' = \tan\theta = \frac{2H}{P}$ at $x = 0$. If this is substituted in Eq. 8, one obtains:

$$\frac{2H}{P} = \frac{P}{2H}\left(\sec\frac{kL_0}{2} - 1\right) - ck\tan\frac{kL_0}{2} \quad \text{(Exact form, no friction)} \quad \ldots (9)$$

This equation may be used to compute the horizontal thrust, H, for any given sets of P, E, and I. A trial and error procedure is required. Once H is calculated, the simple flexure formula may be corrected to allow for both the bending and the compression caused by H, using Eq. 5 given above.

The behavior of a beam loaded at the midpoint, supported at the ends, and which has horizontal components of force at the end supports is somewhat similar to the behavior of a compressed column subjected to a single lateral load. The latter case is considered in a monograph by Timoshenko (15) and served as a guide for the development of Eq. 9 above. This equation is analogous, but not identical, to that of Timoshenko.

Equation 9 has the undesirable feature of requiring a trial and error solution, but fortunately an excellent approximation may be employed frequently. By mathematical manipulation the approximate expression

$$H = P^2L_0^2/(32EI)$$

$$\text{(Approximate form, no friction)} \quad (10)$$

is obtained. For beams no thicker than 1 in. and with customary span-depth ratios, the error inherent in the approximations amounts to about 2.5 per cent for $\frac{L_0}{2}\sqrt{\frac{H}{EI}} = \frac{1}{4}$. For greater values of $\frac{L_0}{2}\sqrt{\frac{H}{EI}}$, the error increases.

Equation 10 is useful for predicting the horizontal thrust and for predicting the magnitude of its effect on the results of a flexure test. The approximate value of H is usually sufficient for substitution in Eq. 5 to estimate the correction called forth by H. Combining Eqs. 5 and 10:

$$S_{\max} = \frac{3PL_0}{2bd^2}(1 + \lambda) \ldots \quad (11)$$

where λ is given by $PL_0\,(6\Delta - 4d)/(48EI)$. The magnitude of λ is discussed later as the data are presented.

Correction for Both Horizontal Thrust and Span Shortening:

It is possible to combine the results of the two previous derivations and thus to make simultaneous corrections for horizontal thrust and for span shortening. This was carried out, but the resulting relationship is so complicated as to discourage its use. It is more practical to correct successively for horizontal thrust and span shortening, using the methods above.

Correction for Large Slopes of Neutral Axis:

When the slope, y', of the beam neutral axis is not small compared to unity, one cannot use the simple relationship between the derivative of the slope, y'', and the radius of curvature of the beam itself, ρ:

$$1/\rho = y'' \qquad \text{(Approximate)}$$

Instead, the exact relationship between the three values must be employed:

$$1/\rho = y''/\,[1 + (y')^2]^{3/2} \qquad \text{(Exact)}$$

This is inconvenient to use because the solution for the deflection is in the form of an infinite series. Boyd (2) integrates the above expression for the case of a cantilever beam bearing one concentrated load at the free end. With Boyd's solution to this one case as a guide, it is straightforward to derive the series applicable to simple beams. The soluton will not be carried out here, for the interested reader may follow Boyd's procedure.

The slope of the neutral axis at the end supports becomes:

$$y' \text{ (at } x = 0) = \frac{-1}{\sqrt{\left(\frac{16EI}{PL_0^2}\right)^2 - 1}} \qquad \text{(Exact)} \ldots \quad (12)$$

The approximate form, found by using the common assumption of $y'' = 1/\rho$ is:

$$y' \text{ (at } x = 0) = \frac{-1}{\frac{16EI}{PL_0^2}} \qquad \text{(Approximate)} \ldots \quad (13)$$

Actually, the approximate form is usually satisfactory. At low loads, that is low values of P, Eqs. 12 and 13 give the same results to three or four significant figures. Even under more drastic conditions the agreement is good. Using some data for vulcanized fiber near its breaking point at a span-depth ratio of 16:1, the exact equation gives a predicted slope of 0.1655 while the approximate form gives 0.1635. These values are in good agreement with one another but they are far less than the measured value of the slope, which was about 0.5; this is because Eqs. 12 and 13 were derived with the horizontal thrust neglected. Nevertheless, since this specimen showed the greatest amount of bending (compared to the span) in any of the tests in which the slope was measured, it is sufficient to demonstrate that the use of Eq. 12 does not yield a correction of the first order. The correction is much less than that caused by horizontal thrust.

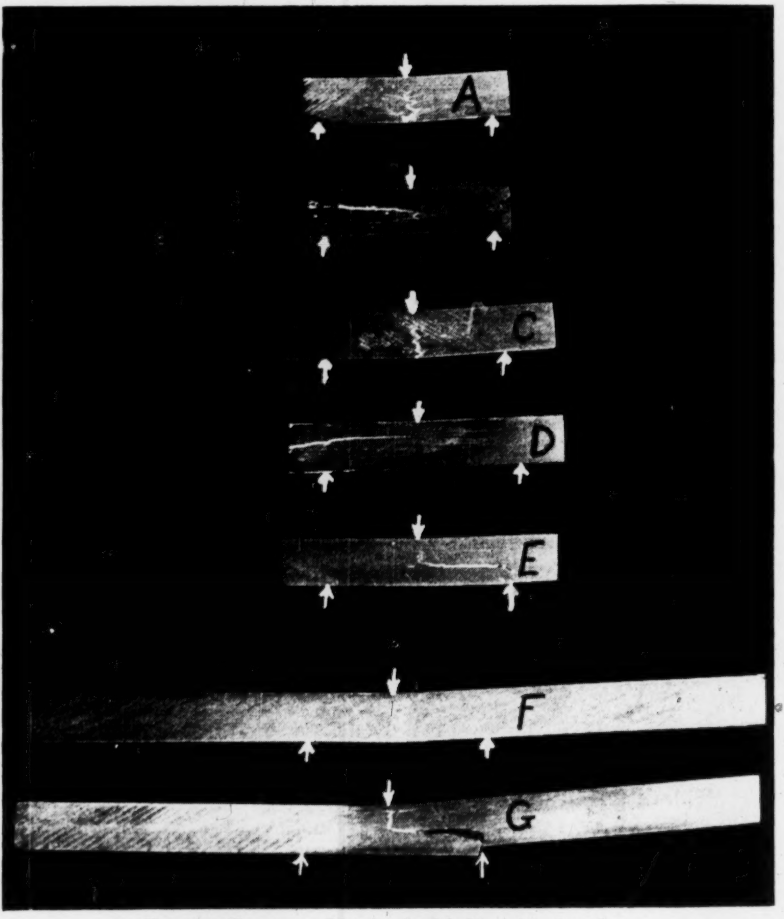

FIG. 6.—Fractures Obtained with Variable Overhang.

Grade X Laminate. Overhangs of 1/16, ¼, 1½ in.

If a prediction of deformation is desired, the series expression is required:

$$y = \frac{PL_0^2}{16EI}x - \frac{Px^3}{12EI} + \frac{1}{2}\left(\frac{P}{4EI}\right)^3 \left(\frac{L_0^6 x}{64} - \frac{L_0^4 x^3}{16} + \frac{3L_0^2 x^5}{20} - \frac{x^7}{7}\right) + \cdots \quad \ldots\ldots(14)$$

For deflections of about 8 or 10 per cent of the span, the deformation calculation is changed by about 2 per cent by using Eq. 14 instead of the common form. Note that the common form may be obtained from Eq. 14 by dropping all but the first two terms on the right-hand side of the equation.

A more recent treatment of the problem of large curvature of beams is given by Bisshopp and Drucker (1). Elliptic integrals are used and no reference is made to Boyd's method.

Correlation Between Tension, Compression, and Flexure:

According to theory, the stress-strain behavior of a material in tension and compression should be sufficient to predict its behavior in pure bending. Nadai (10) outlines the method and derives the equation:

$$M = \frac{PL_0}{4} = \frac{bd^2}{(e_t + e_c)^2}\int_{-e_t}^{e_c} S\cdot e\cdot de \tag{15}$$

Shear stresses are neglected, and it is assumed that a plane cross-section of the beam before bending remains plane as the load is applied. The loading contacts are assumed not to give rise to special stress concentrations. The derivation of the equation is too lengthy for reproduction herein. The development shows that work done in producing pure bending of a bar is equally divided into work of compressing the fibers subjected to compression and work of stretching the fibers subjected to tension.

Since simple beams as frequently tested (three contact edges) do not undergo pure bending, the above equation should not apply strictly. However, even in such cases it might be expected often to be a close approximation.

DISCUSSION OF RESULTS

Overhang at Ends of Beam:

As one portion of the investigation, a systematic study of the possible effects of beam overhang was undertaken. Simple beams having span-depth ratios of 4, 8, 12, and 16 were used. The beam overhang at each end varied from as little as 6 per cent to as much as 150 per cent of the span. A paper-base phenolic laminate (grade X) and a cloth-base phenolic laminate (grade C) were used as examples of stiff materials, while vulcanized fiber (Bone grade) was chosen as a ductile material. Detailed specifications for these materials are available in A.S.T.M. Tentative Specifications for Laminated Thermosetting Materials, D709 - 46T[6] and in Tentative Specifications for Vulcanized Fibre Sheets, Rods and Tubes used for Electrical Insulation, D710 - 43T[7].

Within the range of variables studied, the effect of beam overhang was found to be insignificant with respect to breaking load, deflection at break, and modulus of elasticity. However, at small span-depth ratios the mode of failure was influenced by the amount of overhang. Photographs of typical failures at a small span-depth ratio are shown in Fig. 6.

For elastic materials, horizontal shear is inversely proportional to span-depth ratio. At a span-depth ratio of four, horizontal shear is frequently quite appreciable. Twenty-six tests reported herein (grade-X, 1-in. span, $\frac{1}{4}$-in. depth, $\frac{1}{2}$-in. wide) were made at a 4:1 ratio. The overhang for these tests was varied from $\frac{1}{16}$ in. at each end to $1\frac{1}{2}$ in. Most of the samples at each overhang gave normal failures, with the bottom fibers breaking, in tension at the span center. Examples are specimens A, C, and F in

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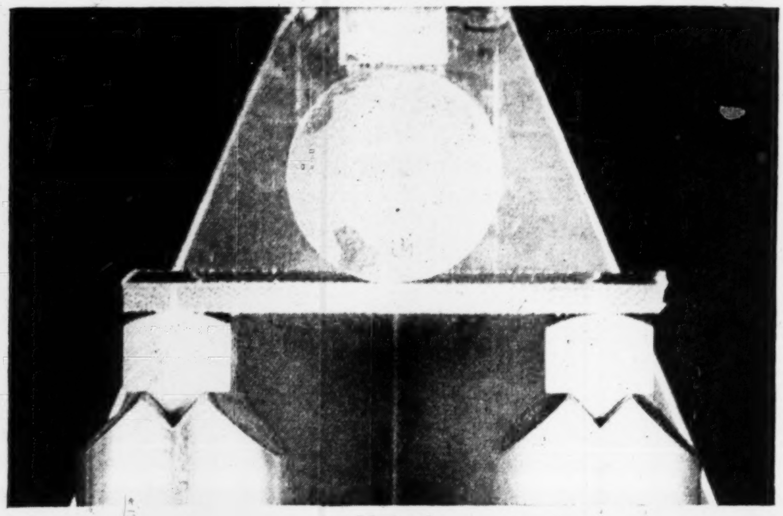
[6] 1948 Supplement to Book of A.S.T.M. Standards, Part III-B, p. 43.

[7] *Ibid.* p. 56.

Fig. 6. However, for the smallest overhang some pure shear failures were noted. All were of the type shown for specimen B in Fig. 6. This shear break extended all the way to the sample end, passing through the overhang portion. Similar pure shear fractures extending through the overhanging end occurred for overhangs of $\frac{1}{4}$ in.: specimen D, Fig. 6, is an example. For the large overhand, $1\frac{1}{2}$ in. at each end, no shear failures extending into the overhang were observed. Specimen G in Fig. 6 shows that when a shear fracture did occur, it did not progress beyond the beam support. For this case, the sample cracked



No load.

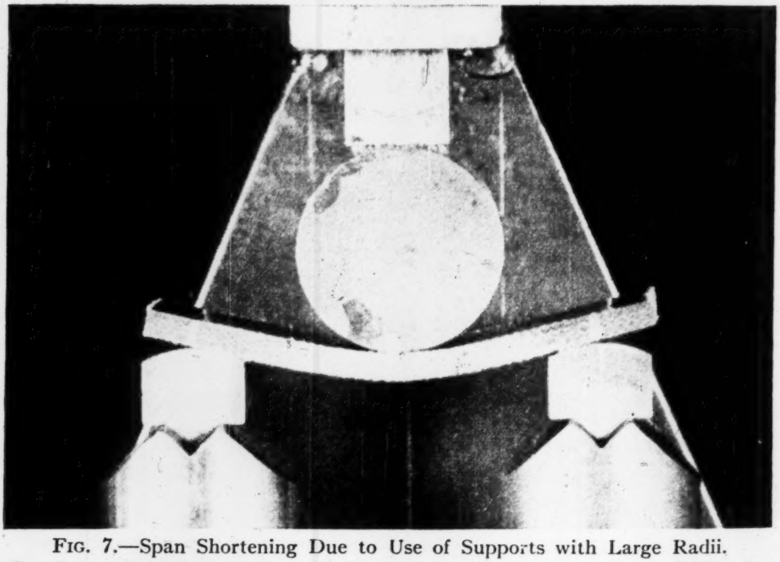


FIG. 7.—Span Shortening Due to Use of Supports with Large Radii.
Radius of curvature of all contacts = ½ in. Beam span = 2 in., thickness = ⅛ in., grade C laminate.

at the end supports due to the stress concentrations there, and this failure progressed upward to meet the shear fracture. This kind of combined-stress failure occurred also for samples with the intermediate overhang (specimen E, Fig. 6, is an example), but it did not occur for any samples having $\frac{1}{16}$-in. overhang.

It is concluded that a large amount of beam overhang may be used to minimize occurrence of pure horizontal shear failures for materials of low span-depth ratio subjected to flexure, but it does not follow that a strength increase will be obtained. It is conceivable that the initiation of failure is due to combined stresses and that after failure is initiated it may progress in either tension or shear.

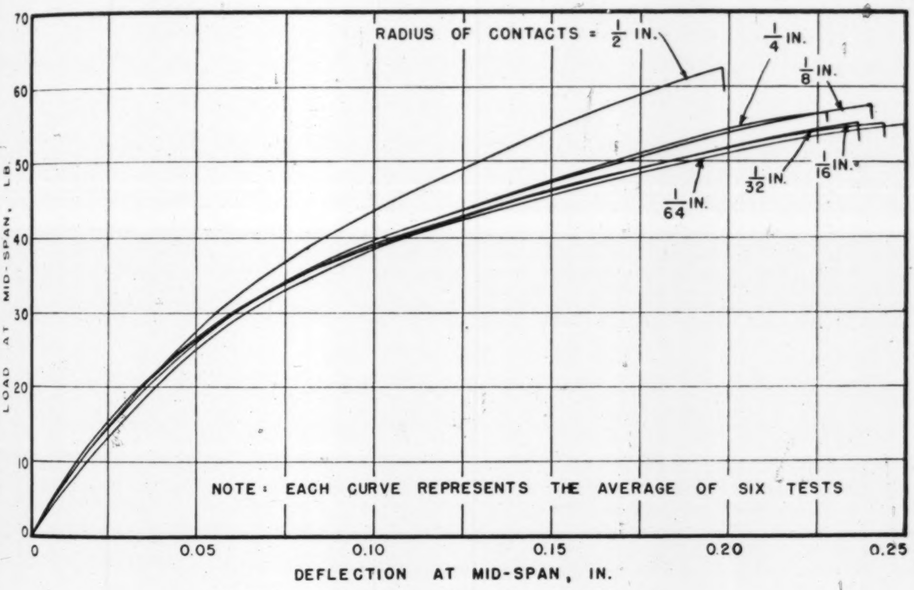


FIG. 8.—Effect of Radius of Loading Edges.
Grade C laminate, span = 2.00 in., width = 0.500 in., thickness = 0.131 in.

Radii of Loading Edges:

Since a contact edge radius of zero corresponds to a sharp knife-edge while an infinite radius corresponds to a uniformly distributed load, it is obvious that flexural strength must be a function of loading edge radii. The load required to cause failure is quite different for these two extreme cases. Various committees of the Society concerned with testing of plastic materials have been unable to agree as to what constitutes a proper loading edge radius; several different radii are specified in the different methods.

Some data obtained by H. K. Nason (**19**) with beams of polystyrene and of cellulose acetate using loading edge radii of from $\frac{1}{64}$ in. to 1 in. indicate that this variation in radii does not affect the flexural properties of these materials The beams were $\frac{1}{2}$-in. thick, and the span was held at 4 in. Even photoelastic studies failed to indicate any differences in stress concentrations at the supports for the different radii.

Since cellulose acetate and polystyrene are very ductile materials and would, therefore, be capable of relieving stress concentrations, it is conceivable that extreme differences in loading edge radii are required to produce a noticeable change in their behavior in flexure. For this reason, two plastic materials of poor ductility (relative to cellulose acetate) were tested as beams using various contact radii. The test apparatus used by Nason was made available for certain of the tests reported herein.

A change in radii of the loading edges causes a number of effects, two of which are the span shortening during deflection and indentation as load builds up at the loading edges.

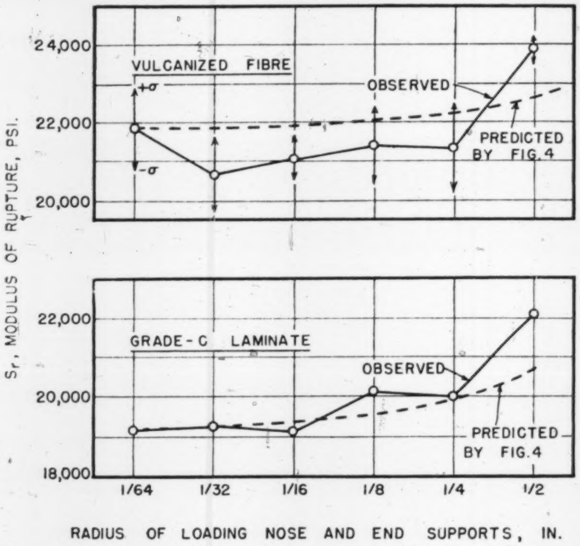


FIG. 9.—Effect of Radius of Loading Edges.

Upper graph: vulcanized fiber, span = 3.00 in., width = 0.500 in., thickness = 0.260 in. Lower graph: grade C laminate, span = 2.00 in., width = 0.500 in., thickness = 0.131 in. NOTE.—Each point represents the average of 6 tests.

1. *Span Change.*—At the start of a flexure test, a simple beam is in contact with the loading edges at three locations as shown in the upper view of Fig. 7. As the load is applied, the point of contact at each of the outer supports shifts inward and downward, moving along the surface of each support. This is evident in the lower view of Fig. 7. For this particular example, a $\frac{1}{8}$-in. thick material at a 16:1 span-depth ratio with $\frac{1}{2}$-in. radius contacts, the span decreased by 10 per cent.

The effect of loading edge radii on shortening of span may be worked out mathematically as shown above. However, changes of loading edge radii may also affect the indentation at the supports, horizontal thrust at the supports, and perhaps other factors as well.

The load *versus* deformation curves obtained with six sets of loading edges are shown in Fig. 8 for a cloth-base phenolic laminate. The curves for the $\frac{1}{64}$-, $\frac{1}{32}$-, and $\frac{1}{16}$-in. radii are close together, but the larger radii give higher curves. Each curve shown represents the average for six tests. The curves shown in Fig. 8 are all corrected to a constant sample width of 0.500 in. and a fixed thickness of 0.131 in.

It is of interest to see whether the effect of supporting edge radii agrees quantitatively as well as qualitatively with the derived relationship. The modulus of rupture obtained with the $\frac{1}{64}$-in. contacts was, therefore, defined as standard and values of the modulus of rupture for other contacts were pre-

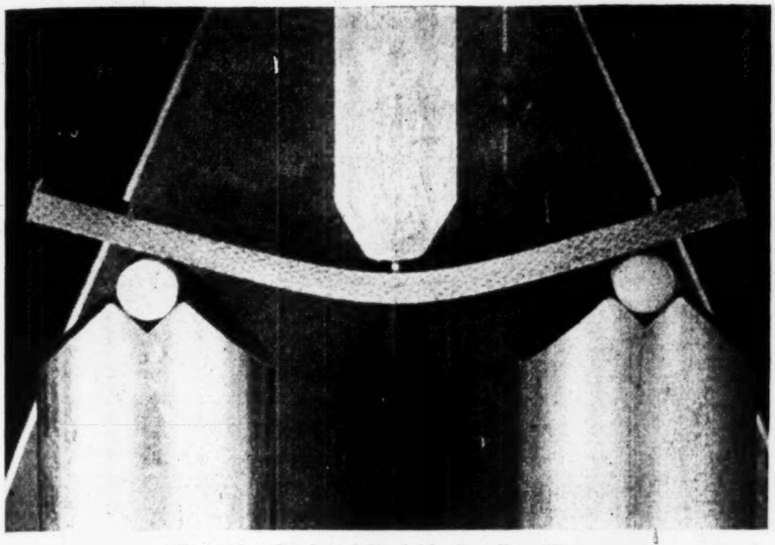


FIG. 10.—Study of Variable Loading Nose.
Nose radius = 1/64 in., support radii = 1/8 in., load = 62.5 lb.

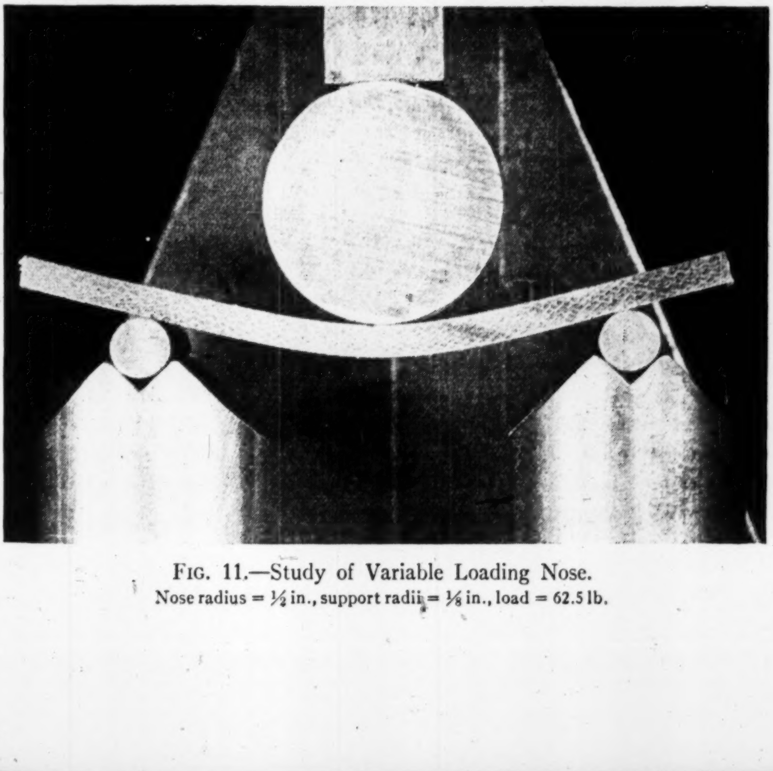


FIG. 11.—Study of Variable Loading Nose.
Nose radius = 1/2 in., support radii = 1/8 in., load = 62.5 lb.

dicted from Eq. 3. The results are shown in the lower half of Fig. 9. The predicted effect is seen to be in the correct direction, but the observed increase in the apparent modulus of rupture is seen to be more than is predicted, especially for the larger radii.

The upper half of Fig. 9 shows a comparison of theory and experimental results for vulcanized fiber, tested with different contacts. If the data for the $\frac{1}{64}$-in. contacts are retained, the agreement between observed and estimated values is poor. On the other hand, if it is assumed that at a radius of $\frac{1}{64}$ in. the contacts begin to cut or otherwise damage the vulcanized fiber, then the remainder of the data agrees with the theory as well as do the data for the harder material, grade C laminate. Therefore it is concluded that an increase in the radius of the supporting edges will lead to an apparent increase in beam strength and that a conservative estimate of the new strength value may be obtained from Fig. 4.

Although it was reasonably certain that the principal effects of varying the loading edge radius were due to span-shortening, at least for the relatively hard grade C material, a separate series of tests was made to demonstrate the fact. For the new tests on the grade C laminate, only the radius of the middle nose was varied. The end contacts were kept constant at a radius of $\frac{1}{8}$ in. Even without a statistical analysis, it was quite apparent that the middle loading nose did not have a noticeable effect on modulus of rupture, modulus of elasticity, or deflection at break. Some photographs, of which two are included, were taken during these tests. An examination of the pictures, Figs. 10 and 11, shows that the area of contact between the middle loading nose and the test specimens is quite small, even for the large loading nose. In addition, the radius of curvature of the beams at the midspan is practically the same in both tests.

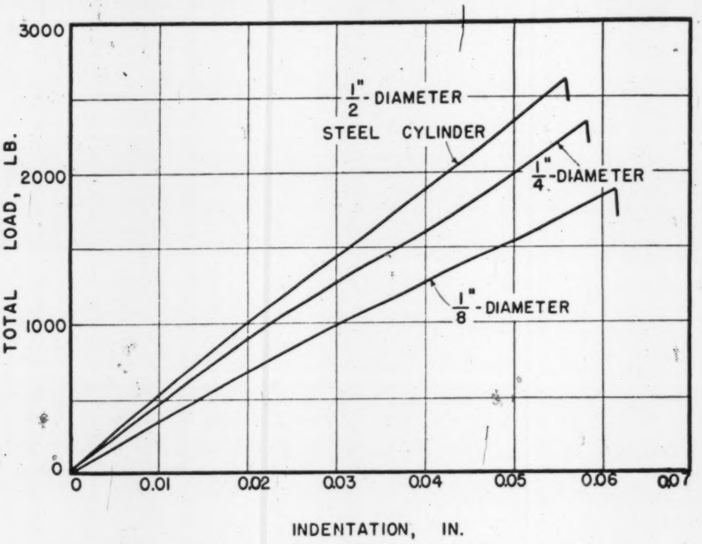


FIG. 12.—Indentation of Cylinders into Vulcanized Fiber.
Sample width = ½ in., thickness = ¼ in., loading rate = 3000 lb. per min.

2. *Indentation.*—When a plastic material is tested as a beam, the indentation which occurs at the contact edges is

usually great enough to be easily visible. It seemed advisable to make an estimate of the type of stresses set up at the supports and to determine the load *versus* indentation relationship existing at the supports. The latter relationship is particularly important since most deflectometer tools, including the one used for the flexural tests in this laboratory, measure indentation at the supports as well as beam deflection whenever a flexure test is made.

Indentation data for cylinders pressed into a cloth-base phenolic laminate, cellulose acetate, and vulcanized fiber were obtained, and part of these are shown in Fig. 12. Each curve shown was obtained by carefully averaging curves for five duplicate specimens.

An attempt to correlate results using

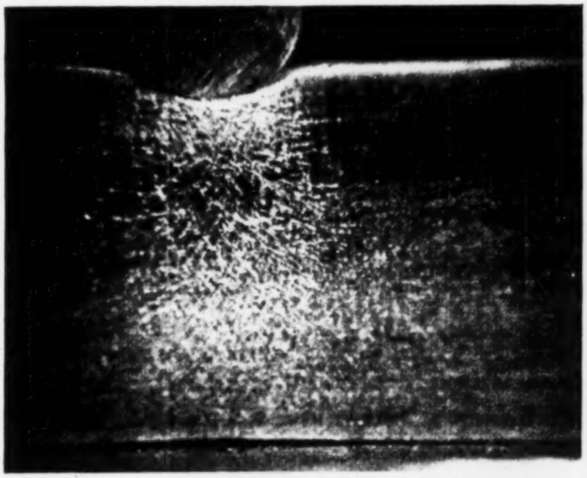


FIG. 13.—Indentation Study of Vulcanized Fiber.
Diameter of indenter = ⅛ in., load = 4000 lb. per in. of width.

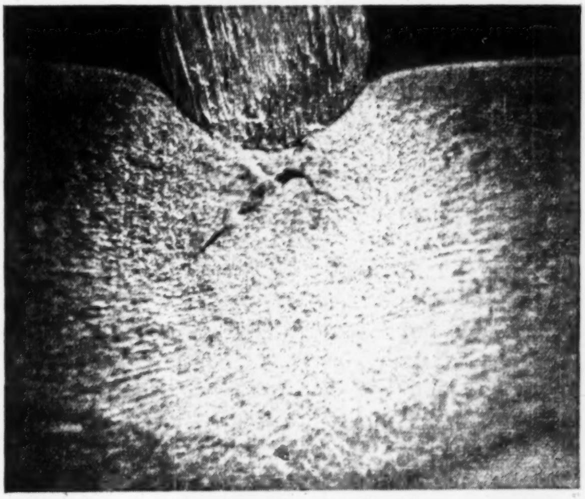


FIG. 14.—Same as Fig. 13.
Load = 5360 lb. per in. of width.

the different sizes of indenters led to only approximate results. It was found that the volume of displaced plastic is almost proportional to the load applied taken to the three-halves power. To determine the "displaced volume" of plastic, indentations were measured; this procedure actually leads to a measure of the volume of displaced space passed through by the indenter in its relative motion.

An important question which may be answered by use of the indentation data is whether the amount of indentation which occurs during a flexure test is sufficient to produce an important error in the deflection measurements. With the deflectometer used for the flexure tests reported herein, any indentation at the two end supports was recorded as deflection. Indentation caused by the middle loading nose was not recorded. Use of the indentation data to estimate the amount of indentation at the end supports shows that for no test included in this study was the indentation at break more than 1.6 per cent of the sample deflection. For most of the tests included herein, the indentation amounted to less than one per cent of the deflection. This error in the deflection measurements is not considered to be important.

It is interesting to note the large difference between the indentations for different materials. For example, considering a load of 100 lb. on a $\frac{1}{8}$-in.-diameter cylinder on a sample 1 in. wide, the indentation is 0.002 in. for cellulose acetate, 0.0015 in. for vulcanized fiber, and 0.0007 in. for grade C laminate.

Some interesting photomicrographs are shown in Figs. 13 and 14. A striking fact is that these figures show curved interesecting slip lines. Lines of this type have previously been discussed by Nadai (9) and others for elastic bodies in contact, and it has been shown that the lines are caused by shear slippage occurring along lines of principal stress. The shear stresses approach very high values at the contact surface, and in Fig. 14 it is seen that two major shear cracks extend outward from the contact area.

Horizontal Forces at End Supports:

During the bending of a beam, its natural stiffness tends to push apart the supports, while the friction between the beam and supports tends to pull the supports together. A simple determination of the role of friction was made by conducting flexure tests in the usual manner and then duplicating the tests, using a lubricant on the end supports. Eighteen specimens of grade X, paper-base phenolic laminate were tested at a span-depth ratio of 8:1, half being used with lubricated supports (a general-purpose grease was employed) and half with "dry" supports. The experiment was later repeated using ten pairs of samples but with a span-depth ratio of 16:1. The specimens were $\frac{1}{2}$ in. wide, $\frac{1}{4}$ in. thick, and rested on $\frac{1}{32}$- in. radii supports. An analysis of the values by means of the common t-test shows no statistically significant difference between specimens tested dry and those tested with greased contacts. This result means that no appreciable frictional forces exist at the beam supports for this one material tested on $\frac{1}{32}$-in. radii. It is highly probable that many other materials behave in a similar manner. If no friction exists, then an outward thrust only is exerted on the supports, and in the elastic region this may be estimated mathematically as outlined in the section on Theoretical Considerations.

Equation 9, and its simplified approximate form, Eq. 10, describe mathematically the idealized relationship between the horizontal thrust and the load at mid-span. Plots of these two variables, using Eq. 9, are shown in Fig. 15 as dotted lines. For the fully-loaded vulcanized fiber at a span-depth ratio of 16, the predicted horizontal thrust amounts to 9 per cent of the central load or 18 per cent of the vertical reaction at each support. In order to test the derived equation, a measurement of the actual horizontal force was desired. However, since a measurement of this type would be rather difficult, the equation $y' = 2H/P$ was used to calculate the horizontal thrust from the observed slope of the beam at the support and the load at mid-span. A number of rough slope measurements were made, and the corresponding H values were computed. The values are shown plotted in Fig. 15. It is apparent that the derived equation gives a correct qualitative interpretation of the data, but that the predicted quantitative values are somewhat low in all cases.

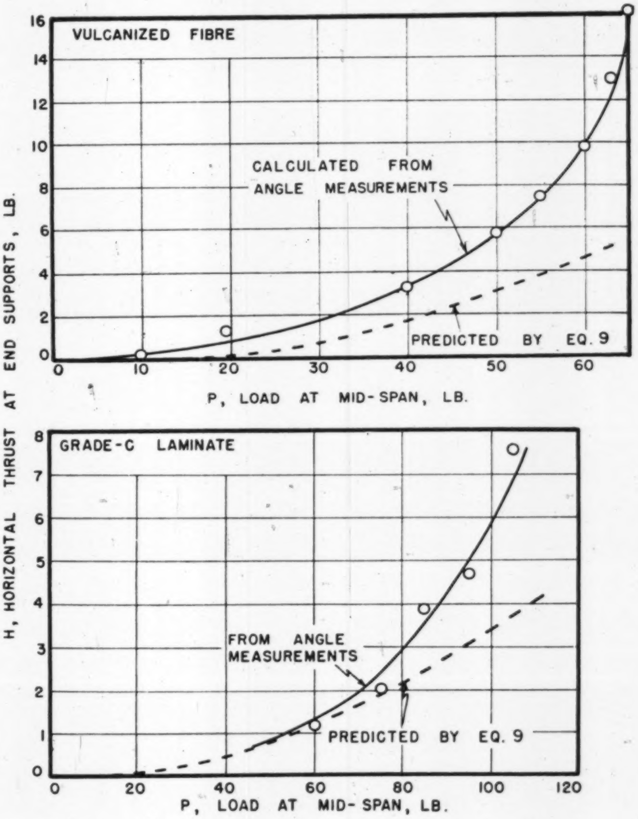


FIG. 15.—Horizontal Thrust at End Supports.

Upper graph: vulcanized fiber, test No. 1976, span = 4.00 in., width = 0.260 in., thickness = 0.263 in.; lower graph grade C laminate, test No. 1979, span = 2.00 in., width = 0.254 in., thickness = 0.259 in. radius of all contacts = $\frac{1}{8}$ in.

The error in the calculated modulus of rupture due to the horizontal thrust is indicated by the value of λ in Eq. 11. For the two tests shown in Fig. 15, λ is -0.003 (for the grade C material at 8:1 span-depth ratio) and $+0.028$ (for the vulcanized fiber at 16:1 span-depth ratio). Measured values of P and Δ were used in computing these values. This means that the maximum predicted correction to the modulus of rupture is 2.8 per cent for these two cases. The one negative value of λ means that for that case the bending moment due to the horizontal forces opposes the bending due to the central load. The positive value of λ means that the moments are in the same direction. It is clear that a predicted moment correction of more than 2 or 3 per cent is required only for a large span-depth ratio, say 16 or more. However, since the results in Fig. 15 indicate that at maximum load the calculated horizontal thrust is about half the "measured" value, one would estimate the error due to moment correction to be about double the value of the calculated λ.

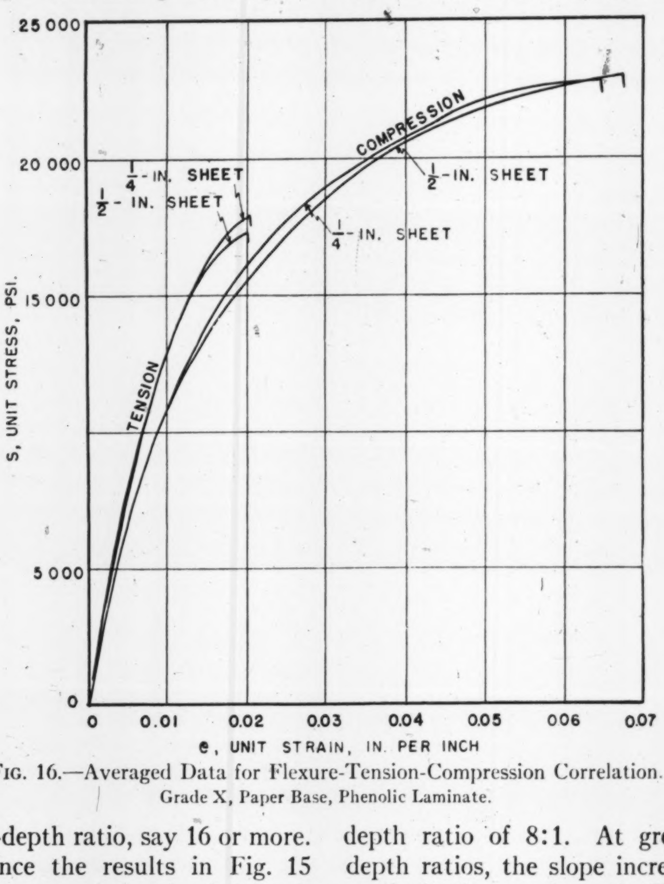


FIG. 16.—Averaged Data for Flexure-Tension-Compression Correlation. Grade X, Paper Base, Phenolic Laminate.

Amount of Curvature:

Since the flexure formula as commonly used is based on an assumption that the slope of the beam neutral axis is small compared to unity at all points, it is important to check this assumption for tests with plastic materials. A few rough measurements of the slope of plastic beams at the ends were made using cellulose acetate, vulcanized fiber and phenolic laminates. It was found that the slopes ranged up to 0.25 for some of the softer materials at a span-depth ratio of 8:1. At greater span-depth ratios, the slope increased. The particular beams shown in Figs. 10 and 11 (grade C laminate) had span-depth ratios of 16:1, and their slopes at the beam ends amounted to about 0.25. The greatest slope measured was 0.5 which was for the vulcanized fiber specimen demonstrated in Fig. 15 and discussed to some extent under Theoretical Considerations. Even this amount of curvature is sufficient to cause only a minor change in the predicted deformation. At loads near the maximum, however, the actual deflection is so different from the predicted deflection that the correction due to curvature is not worth consideration. In addition, the slopes of the beams at the end are not significantly different as predicted by simplified theory and by exact theory, so it is again clear that this correction is usually not of practical significance.

If it is desired to carry through the correction for large beam curvature, however, say for tests in which very large span-depth ratios are used, then the procedure would be to use:

$$y''/[1 + (y')^2]^{3/2}$$

instead of y'' in the previous derivations. The solutions would be infinite series.

Relationship Between Flexure, Tension, and Compression:

The simple flexure formula may be derived by assuming that each fiber in the upper portion of a beam is subjected to pure compression and that each fiber in the lower portion is subjected to pure tension. The amount of strain in any fiber is assumed to be proportional to its distance from the neutral axis. For metals such as common steels, which are used frequently under conditions such that the working stresses are within the elastic range, the assumptions are reasonably valid. In fact, for such materials

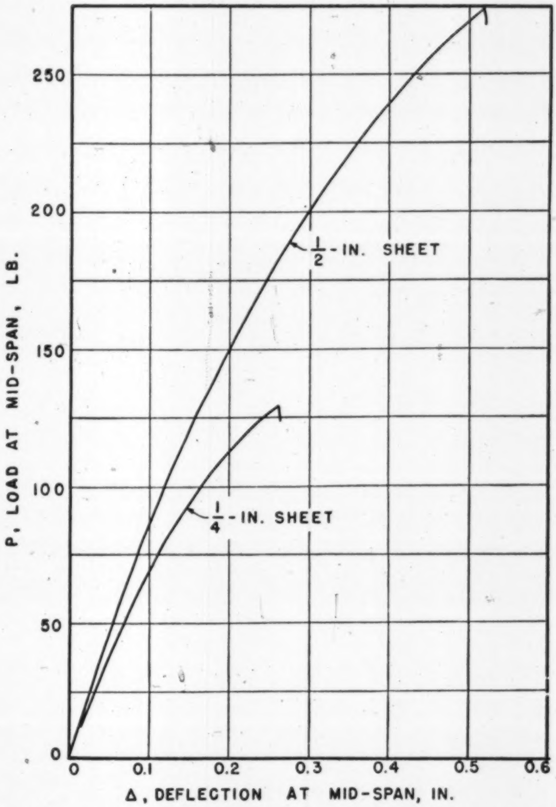


FIG. 17.—Averaged Data for Flexure-Tension-Compression Correlation. Flexure Tests of Grade X, Paper Base, Phenolic Laminate.

it is possible to construct the load-deflection curve for flexure from a knowledge of the tensile and compressive stress-strain curves.

For plastics, however, it is doubtful that each fiber resists a simple tensile or compressive load. Slippage of fibers (or flow of the material) may be considerable (kinking or unkinking of fibers may be important also), and the details of test technique that could affect such factors (speed of loading is a prime example of a factor affecting flow) may play a much more important rôle for plastics than for metals. Thus, the degree to which a flexure curve for a plastic can be correlated with tensile and compressive data on the same material is an indication of how important the test variables are. If a poor correlation is demonstrated, one must conclude that for plastics the individual fibers are subject to complex stresses and that the simple flexure formula should not be expected to give reliable results.

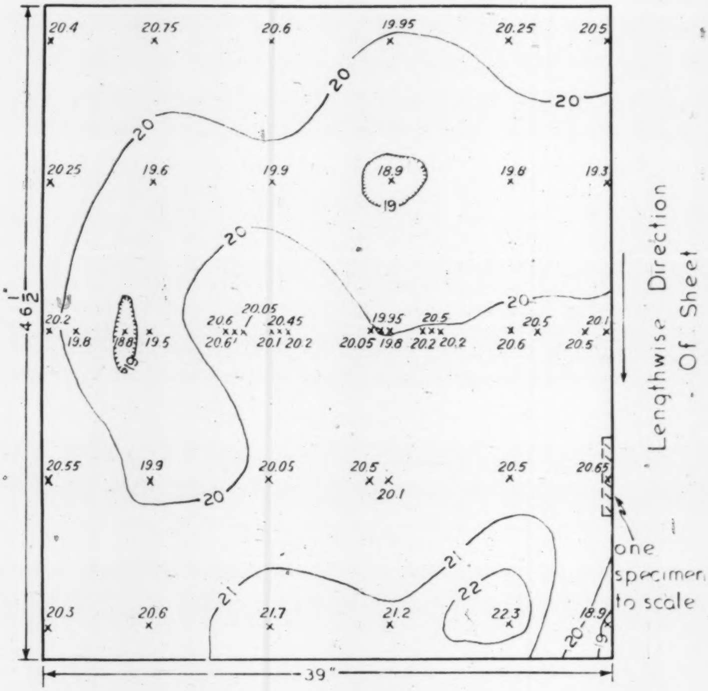


FIG. 18.—Flexural Strength Survey.

½-in. sheet, grade C, cloth base, phenolic laminate, size of specimen: 5 by ½ by ½ in. (span = 4 in.) orientation of specimen: lengthwise. Values given are thousands of pounds per square inch.

A brief investigation was carried out to obtain flexure, tension, and compression data under comparable conditions. Two separate sheets of grade X laminate were used. One was ½-in. thick from which 6 tension, 9 flexure, and 12 compression specimens were cut. The other sheet was ¼ in. thick from which 8 tension, 12 flexure, and 12 compression specimens were cut. The speed of test was chosen so as to strain the gage lengths at 1 per cent per minute for the tension and compression tests and a rate of 1 per cent per minute for the outermost portion of the flexure specimens.

The observed data are shown in Figs. 16 and 17. Each curve shown is the average of its group of multiple determinations. By use of the tension and compression curves, Nadai's procedure was followed, and predicted flexure break-loads were obtained. The predicted load for the $\frac{1}{4}$-in. specimens was 113.3 lb., which is eleven per cent below the experimental value of 127.8 lb. For the $\frac{1}{2}$-in. specimens the predicted load was 240.5 lb., which is 14 per cent below the experimental value of 278.1 lb. This is interpreted to mean that the assumption that the fibers of a beam are subjected to simple tension or compression loads is not far from the truth. For the present, this conclusion must be restricted to the one material investigated, and to the span-depth ratio of 16.

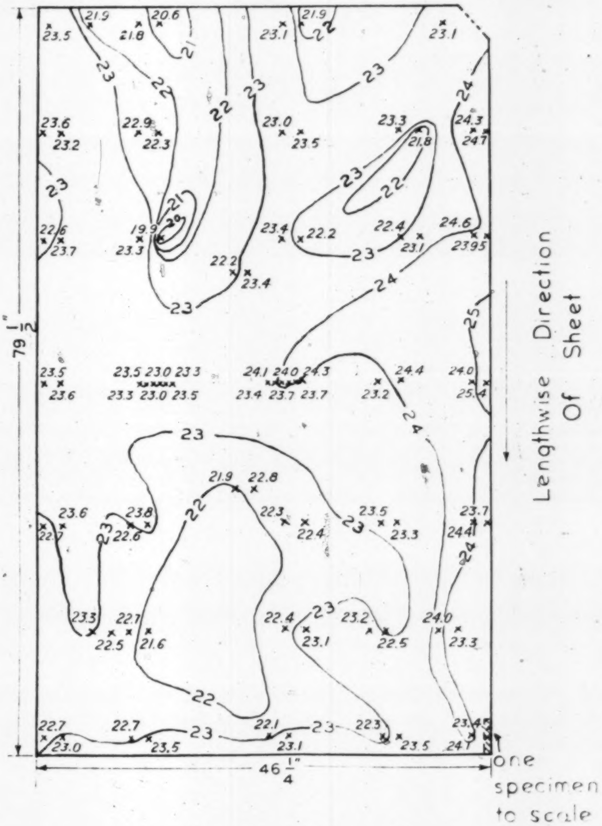


FIG. 19.—Flexural Strength Survey.

¼-in. sheet, vulcanized fiber, bone grade, size of specimen: 3½ by ½ by ¼ in. (span = 2 in.) orientation of specimen: lengthwise. Values given are thousands of pounds per square inch.

Variability of Material:

The natural non-uniformity of commerical plastic materials is a factor that must be kept in mind constantly. The variability is so great, as is shown below, that careful sampling techniques are required in order to study almost any physical property of such materials.

Some results obtained by conducting surveys of entire sheets of three commercial plastic materials are shown in Figs. 18 to 20. Since the difference obtained between adjacent samples sometimes was equal to two or three contour intervals, the strict validity of the contour maps, Figs. 18 and 19, is in doubt.

The numerical results of the surveys for eight sheets are summarized in Table I. The natural variations of the sheets are very pronounced. The least variable of the particular sheets investigated, at least from the standpoint of flexural

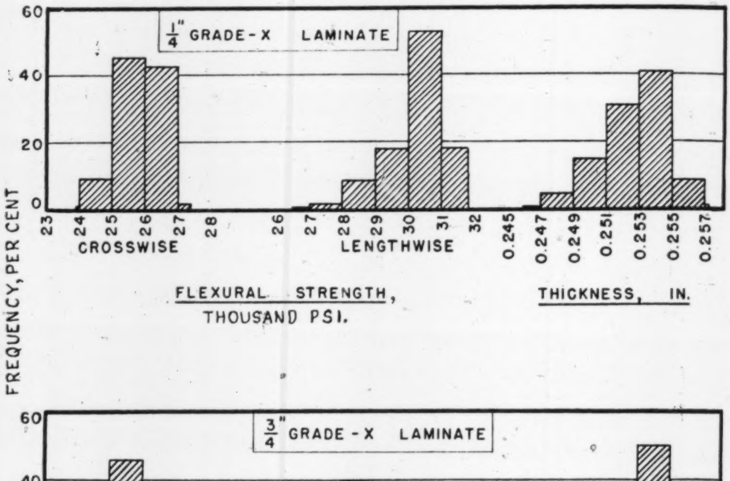


FIG. 20.—Variation of Strength and Thickness for Two Sheets.

TABLE I.—VARIABILITY OF MATERIALS.

Results of Surveys Using Entire Sheets.
N = Number of tests.
σ = Standard deviation.

Material	Nominal Thickness, in.	Flexural Strength Crosswise, psi.					Flexural Strength Lengthwise, psi.					Sheet Thickness, in.			
		Max.	Min.	Avg.	σ	N	Max.	Min.	Avg.	σ	N	Max.	Min.	Avg.	N
Grade X Paper Base Phenolic Laminate	1	26 600	22 800	24 529	839	29	32 200	25 100	28 791	1070	33	1.035	1.011	1.028	62
	¾	25 200	21 500	23 356	841	43	29 900	25 400	27 694	1005	47	0.759	0.733	0.754	90
	½	26 600	22 800	25 055	965	53	32 800	26 800	29 664	1211	44	0.525	0.509	0.520	97
	¼	27 400	23 900	25 710	950	58	31 800	26 500	29 951	1235	49	0.257	0.246	0.253	107
	⅛	29 300	21 800	26 356	1618	54	33 500	25 700	30 388	1840	49	0.129	0.120	0.124	103
	1/16	27 800	21 800	24 810	1176	55	33 000	25 700	29 775	1569	53	0.061	0.057	0.0588	108
Grade C[a]	½	21 300	14 500	20 114	950	57	22 300	18 800	20 225	635	45	0.521	0.493	0.512	102
Vulcanized Fiber[b]	¼	19 900	14 500	16 091	685	76	25 400	20 600	23 156	802	78	0.260	0.251	0.256	154

[a] Cloth-base phenolic laminate.
[b] Bone-grade vulcanized fiber.

strength, was the 1-in. thick grade X laminate. For this material, the variation in flexural strength was from 22,800 to 26,600 psi. crosswise and from 25,100 to 32,200 psi. lengthwise. The standard deviations for both directions amounted to about 3.5 per cent of the mean flexural strength in the direction considered. The most variable sheet was one of the same material $\frac{1}{8}$ in. thick. In this case the flexural strength variations were from 21,800 to 29,300 and from 25,700 to 33,000 psi. for the crosswise and length wise directions, respectively. The standard deviations amounted to about 6 per cent of the mean strength values.

In general, the following observations may be made: The maximum strengths are 20 to 40 per cent greater than the minimum values for any particular sheet, but the standard deviation amounts to only 3 to 6 per cent of the mean strength The latter observation shows that the number of "wild" values is rather small and that the sheets possessed only a few spots that were much stronger or weaker than the remainder. Thin sheets are more variable than thicker ones. The contour patterns are so different for the various sheets, even of the same material, that it becomes apparent that the shape of the diagram is entirely fortuitous and that one diagram cannot be used to predict the variations in any other sheet.

It is obvious that careful sampling procedures are required whenever studies of any test variables are to be undertaken; otherwise, the variation of test material may mask the effects being studied. For all the various investigations reported herein, multiple determinations were made in each test, and the selection of the samples was made in such a manner as to insure each average being representative of the whole.

Choice of Span-Depth Ratio for Test Purposes:

Those interested in setting up standard test procedures find it difficult to decide from experimental data whether it is desirable to specify a large span-depth ratio or a small one. From the preceding, it is possible to reach certain conclusions: namely,

A small span-depth ratio has the advantages of leading to large (and therefore easily measured) break-loads, the slope of the beam is small at all points, the probability of a weak spot being located at or near the center is small, and the horizontal forces developed at the supports are small. It has the disadvantages of leading to small deflections (therefore, difficult to measure), the horizontal shear may be large, the span-shortening due to rolling on the contacts may be great, and the indentation at the contacts may be serious.

On the other hand, a large span-depth ratio has the advantages of leading to large, easily measured deflections, small horizontal shear forces, small span-shortening, and small indentations at the supports. It has the disadvantages of leading to large horizontal reactions at the end supports, small values of break-loads, beam slopes large enough so that the radius of curvature is not inversely equal to the first derivative of the beam slope with respect to horizontal distance, and the probability of a weak spot being near the center is increased. It can only be concluded that there is not a precise answer to the problem which will be suitable for all materials. The author feels that a span-depth ratio of 16 is somewhat more practical than a value of 8 (which is suggested by some), for the advantages of the greater span seem to outweigh slightly the disadvantages.

In the interest of brevity, only the "high spots" of a research program covering several years are reported here. Complete details are to be found in University of Delaware Engineering Experiment Station *Bulletin No. 2.*

CONCLUSIONS

For plastic materials tested as simple beams it is concluded that:

1. Appreciable horizontal reactions may develop at the beam supports. The stresses due to these reactions lead to a decrease in apparent modulus of rupture as span-depth ratio increases. A theoretical prediction of the effect is in fair agreement with experimental data.

2. The radius of the loading edges affects the break-load because of span-shortening that occurs during loading. A theoretical prediction of this effect is in fair agreement with experimental data also.

3. The amount of beam overhang has no effect on flexural strength, provided the overhang is at least equal to the minimum value investigated, that is 6 per cent of the span.

4. The amount of indentation at the end supports is ordinarily negligible; for the tests reported herein, the indentation never exceeded 1.6 per cent of the beam deflection.

5. Friction at the end supports is negligible, at least for the grade X laminate.

6. Theoretical corrections called for because of excessive beam curvature are ordinarily negligible for span-depth ratios of 16 or less.

7. The variability in physical properties of commercial sheets of plastic materials is appreciable, and statistical methods are required to evaluate test data.

NOMENCLATURE

b = Width of beam in inches
c = Distance from neutral axis to fiber of maximum stress (half-thickness of the beam) in inches.
d = Thickness of beam in inches.
e_c, e_T = Unit strain in compression, unit strain in tension in inches per inch.
E = Apparent modulus of elasticity in pounds per square inch.
H = Horizontal thrust at end supports in pounds.
I = Moment of inertia of beam cross-section about the neutral axis, in.^{4}
k = Defined as $\sqrt{H/(EI)}$, in.$^{-1}$
L_0 = Initial span of beam in inches.
M = Bending moment in pound-inches.
M_x = Bending moment in beam at point (x, y), in pound-inches.
P = Load on beam at midspan in pounds.
R = Radius of curvature of a contact edge in inches.
S = Unit stress in pounds per square inch.
S_r = Modulus of rupture, $\frac{3PL}{2bd^2}$, in pounds per square inch.
y', y'' = First and second derivatives of y with respect to x.
α = Defined as $\frac{PRL_0}{EI}$, dimensionless.
Δ = Maximum deflection of beam in inches.
ϵ = Defined as $\frac{2a}{L_0}$, fractional span change, dimensionless.
λ = Defined as $PL_0(6\Delta - 4d)/(48EI)$, dimensionless.
ρ = Radius of curvature of beam neutral axis.

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(19) W. A. Zinzow, "Flexural Properties of Plastics," ASTM BULLETIN, No. 134, May, 1945, pp. 31–37.

DISCCUSSION

MR. W. N. FINDLEY[1] (*by letter*).—Mr. Westwater has presented a very thorough study of a simple test having many complicating factors. The writer has had a prejudice against the use of the static flexure test for studying the effect of different variables on the strength properties of plastics because of some of the complications described in the paper. So I am wondering whether the author feels that there is an advantage in the flexure test compared to the tension or compression test when accurate values of strength and stiffness are required.

It seems to the writer that the corrections needed to obtain accurate values from flexure tests may balance the greater simplicity of the flexure specimen and greater ease of performing the test. There seems to be about equal complexity of apparatus and computations in flexure or tension or compression tests.

MR. J. W. WESTWATER (*author's closure*).—When accurate values of tensile or compressive strengths are needed, those values should be measured as directly as possible. The flexure test is not a substitute for tension and compression tests in such cases. However, for control purposes the flexure test has the advantages of ease of preparation of specimens and ease of carrying out the test. In addition, if a material is to be used to resist bending loads, the flexure test is indicated. The corrections shown in the paper are not required ordinarily, but it is of importance to have them available when needed. The need is serious when one wishes to compare results obtained with materials under different test conditions.

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DAMPING AND RESONANT LOAD-CARRYING CAPACITIES OF POLYSTYRENE AND OTHER HIGH POLYMERS*

By J. A. Sauer[1] and W. J. Oliphant[1]

Synopsis

The present investigation is concerned with the experimental determination of the relation between damping capacity and stress for specimens of polystyrene and some other thermoplastic and thermosetting materials. The damping capacities of these materials are determined by a resonant vibration method and found to increase with stress amplitude approximately to the 2.3 power. Among the thermoplastic materials tested, cellulose acetate butyrate is found to have the highest damping capacity and polystyrene the lowest. Various grades of phenolic laminates show still lower energy absorptions under dynamic tension-compression loading.

An attempt is made to evaluate the design importance of both damping capacity and fatigue strength by setting up an analysis for the determination of the relative load-carrying capacities of a simple member subject to dynamic loads oscillating at resonant frequency. Despite some rather drastic assumptions, comparative rating of the different plastic materials based on resonant load factors would appear to be more significant than comparative ratings based solely on endurance strength or solely on damping capacity. Among the thermoplastics, methyl methacrylate exhibits the highest resonant load values and is about comparable in this respect to the paper-base phenolic laminates.

For polystyrene, it is observed that damping capacity varies with stress amplitude in the same manner as experimental creep rate values vary with applied tensile stress. Comparison of the data show that the creep rate increases approximately as the square of the damping capacity.

For some engineering applications of materials, the designer need only be aware of the elastic properties. In many other applications, however, such as a turbine blade subject to high-temperature steam or a propeller or crankshaft subject to dynamic loads near resonant frequencies, anelastic properties such as creep and mechanical hysteresis become important. It is the purpose of the present paper to examine the anelastic properties of that group of materials known as plastics and to determine the relative load-carrying ability of a number of different plastic materials under resonant or near resonant conditions.

A study of the dependence of two anelastic properties—creep and damping capacity—on stress amplitude has been carried out for a particular thermoplastic material known commercially as Lustrex LX. (This material is a grade of polystyrene having an average molecular weight of approximately 68,000.)[2] Some of the results of this study, in particular the bearing of the data on the internal molecular structure of the material, have been reported elsewhere by Sauer, Marin, and Hsiao (1).[3] The creep-time behavior of this same material under tension, torsion and bending loads is being concurrently reported by Marin and Cuff (2). This paper will, therefore, concern itself almost entirely with the determination of the damping capacity and dynamic modulus of polystyrene and several other thermoplastic and thermosetting materials and with the design aspects of these data.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

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[2] As determined in accordance with the Staudinger technique, at the Plastics Laboratory, Monsanto Chemical Co., Springfield, Mass.

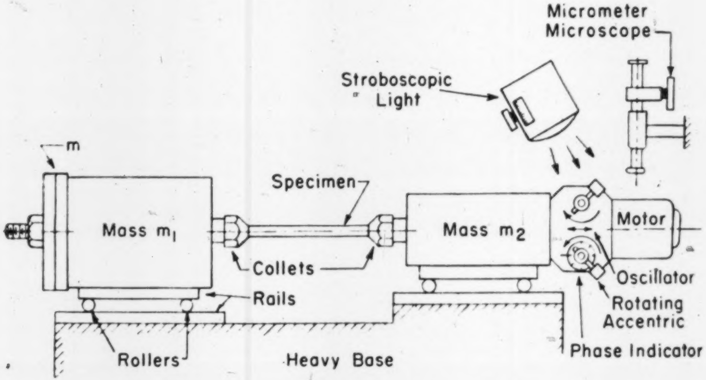

FIG. 1.—Schematic Diagram of Apparatus.

TEST APPARATUS AND PROCEDURE

A number of different methods have been suggested and used by various investigators (3, 4) to determine damping capacity (energy absorbed per cycle per unit volume when a given specimen is subjected to cyclic stress). The method used in the present investigation is a resonance vibration method developed and used by Lazan (5) and by Robertson and Yorgiadis (6) for both metal and plastic specimens.

Figure 1 is a schematic diagram of Lazan's apparatus. The specimen in the form of a solid cylinder is rigidly attached to two large masses (M_1 and M_2) which are supported on frictionless hardened steel rollers. A mechanical oscillator, with adjustable weights (Fig. 2), driven by a synchronous motor is attached to one of the masses. When the motor is turned on, the specimen is subjected to alternating cycles of tension and compression and acts as the spring of a single-degree-of-freedom vibratory system. The masses M_1 and M_2 are varied by the addition or subtraction of small masses, m, until the system is operating at resonance, that is, until the natural frequency of the specimen-mass system is

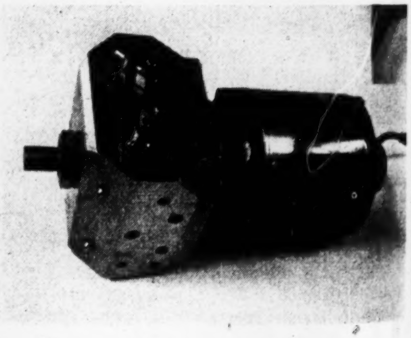

FIG. 2.—Mechanical Oscillator Used for Damping Tests.

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[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1131.

the same as that of the oscillator. This condition is determined by noting the value of the phase angle ϕ between the oscillator force and the displacement and varying the weights until $\phi = 90$ deg.

At resonance, the input energy is almost entirely dissipated through internal friction in the specimen, as energy losses to the supports are small (6). The numerical value of the damping capacity, ΔW, is obtained from the measured value of the displacement amplitude, a, and the known amplitude of the oscillator force, F, by use of the standard formula for the energy absorbed by a single-degree-of-freedom system operating at resonance,

$$\Delta W = \frac{\pi F a}{AL} \quad \text{.........} \quad (1)$$

where A is the cross-sectional area of the specimen and L the specimen length between grips. The amplitude, a, is measured by a micrometer microscope as shown in Fig. 1. The maximum stress produced in the specimen by the oscillating force and the dynamic modulus are given respectively by the following formulas

$$\sigma = \frac{M_2\, \omega^2 a}{A} \quad \text{.........} \quad (2)$$

$$E = \frac{L\omega^2\, M_1\, M_2}{A\,(M_1 + M_2)} \quad \text{......} \quad (3)$$

where ω is the circular frequency of the oscillator.

Tests were run at a series of progressively increasing stress levels obtained by variation of the oscillator weights. In each case, once the resonant condition was reached, readings were taken of the displacement amplitude. From these readings and the known values of the specimen area, specimen length, oscillator frequency, and masses M_1 and M_2, numerical values of damping capacity, stress amplitude and dynamic modulus were obtained directly from Eqs. 1, 2, and 3.

Two cautions were observed in running all tests. First, the stress level was kept below the point at which fatigue cracks originated. For the polystyrene specimens, it was found possible to obtain measurements of damping capacity at stresses as high as 2100 psi. even though this stress is considerably above the endurance limit for this material. This could only be accomplished, however, by using non-metallic fillers between the specimen and the collet to cut down surface abrasion and pitting and by carefully machining the specimen to avoid scratches or cuts. These precautions were found to be considerably more important for polystyrene than for the other thermoplastic and thermosetting materials probably because its brittle nature prevented redistributions of high localized stresses through plastic flow.

The second caution was to make the necessary measurements as quickly as possible (~1 min.) so as not to overheat the specimen and to allow sufficient time between measurements to permit the specimen to cool. As a check on the influence of absorbed heat on the properties of the material, one or more low stress readings of the damping capacity were repeated for each polystyrene specimen after completion of the damping tests taken over the whole range of stresses. In each instance, these readings checked closely with the original ones (1).

TEST MATERIALS AND TEST SPECIMENS

Although more complete data were taken for polystyrene than for any other material, determinations of damping capacity as a function of stress amplitude were made for several other thermoplastic materials and also several phenolic laminates. The thermoplastic materials

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included cellulose acetate, cellulose acetate butyrate and methyl methacrylate, while the thermosetting ones included phenolic laminates with paper base, fabric base, army duck base, rayon base, and asbestos base. A short description of these materials is given in Table I.

The polystyrene (Lustrex LX) test specimens were cut from molded flat sheets 12 in. wide and 12 in. long. They varied in thickness from $\frac{3}{4}$ to 1 in. All sheets were examined under polarized light before use and those sheets showing noticeable internal strains were discarded. Tension and compression control tests performed at room temperatures revealed the material to have a modulus of elasticity of 4.5×10^5 psi., an average tensile strength of 5700 psi. and a compressive yield strength (based on a 0.005 offset) of 12,400 psi. Details of testing procedure as well as stress-strain curves and values of other mechanical properties are given elsewhere (1, 2). The tests indicated that at room temperatures under tension loading the material was quite brittle in nature with very little plastic yielding before fracture.

TABLE I.—DESCRIPTION OF THERMOPLASTIC AND THERMOSETTING MATERIALS USED IN PRESENT INVESTIGATION.

Thermoplastic Materials:

Cellulose Acetate.—Test specimens made from compression molded rod, grade FM6, medium soft, with 40 parts triacetin plasticizer. Supplied through the courtesy of Monsanto Chemical Co.

Cellulose Acetate Butyrate.—Test specimens in form of molded 1-in. diameter tubes made from medium hard grades Tenite II, 201 and 203. Supplied through courtesy of Tennessee-Eastman Corp.

Polystyrene.—Test specimens in form of Styron rod supplied through courtesy of Dow Chemical Co.

Methyl Methacrylate.—Test specimens made from "Type 1—General Purpose" cast Plexiglas supplied through courtesy of Rohm & Haas Co.

Thermosetting Materials—Laminated Phenolics:

Paper Base.—Molded from high strength Mitcherlich paper with a fast curing phenol formaldehyde resin at a temperature of 310 ± 10 F. and at a pressure of 250 psi. Laminations are parallel. Sheets supplied through courtesy of Consolidated Water, Power and Paper Co.

Rayon Base.—Molded at a temperature of 320 F. and a pressure of 1100 psi. with crossed rayon-cotton fabric base. Sheets supplied through courtesy of Formica Insulation Co.

Asbestos Base.—Test material supplied in form of ¾-in. diameter tubes through courtesy of Synthane Corp.

Army Duck.—Molded with square army duck and a fast curing phenol formaldehyde resin at a temperature of 320 F. and a pressure of 180 psi. Parallel laminations. Supplied through courtesy of Synthane Corp.

Paper Base (Grade XX).—A paper base laminate supplied in the form of ½-in. diameter rods by the Synthane Corp.

Fabric Base (Grade L).—A fine weave fabric base laminate supplied in the form of ¾-in. diameter tubes through courtesy of the Synthane Corp.

TABLE II.—TYPE AND DIMENSIONS OF DAMPING TEST SPECIMENS.

Type of Plastic	Type of Specimen	Cross-sectional Dimensions, in.	Length of Specimen, in.	Frequency of Oscillation, cycles per sec.
Polystyrene (Lustrex LX)	Rod	0.622 round	9.12	26.6
OTHER THERMOPLASTIC MATERIALS				
Cellulose acetate butyrate (201-MH)	Tube	O.D. = 1.000 I.D. = 2.865	7.06	18.0
(203-MH)	Tube	O.D. = 1.004 I.D. = 0.811	9.75	18.0
Cellulose acetate (FM6)	Rod	0.500 round	7.31	18.0
Methyl methacrylate (Plexiglas)	Rod	0.749 round	6.25	37.5
Polystyrene (Styron)	Rod	0.502 round	7.31	26.6
THERMOSETTING PHENOLIC LAMINATES				
Army duck base	Rod	0.513 × 0.500	9.00	37.5
Fabric Base (grade L)	Tube	O.D. = 0.750 I.D. = 0.500	10.87	37.5
Paper base (grade XX)	Rod	0.500 round	8.00	37.5
Asbestos base	Tube	O.D. = 0.750 I.D. = 0.496	12.94	37.5
Rayon base	Rod	0.508 × 0.615	7.50	60.0
Paper base (high strength)	Rod	0.502 × 0.508	8.94	60.0

The damping tests on polystyrene were made on cylindrical specimens $\frac{3}{4}$ in. in diameter in the collets and 0.622 in. in diameter in the center section between collets. The over-all length of the specimens was 12 in. and the length between collets approximately 9 in. The specimens were held for at least one week prior to testing in a storage chamber at a

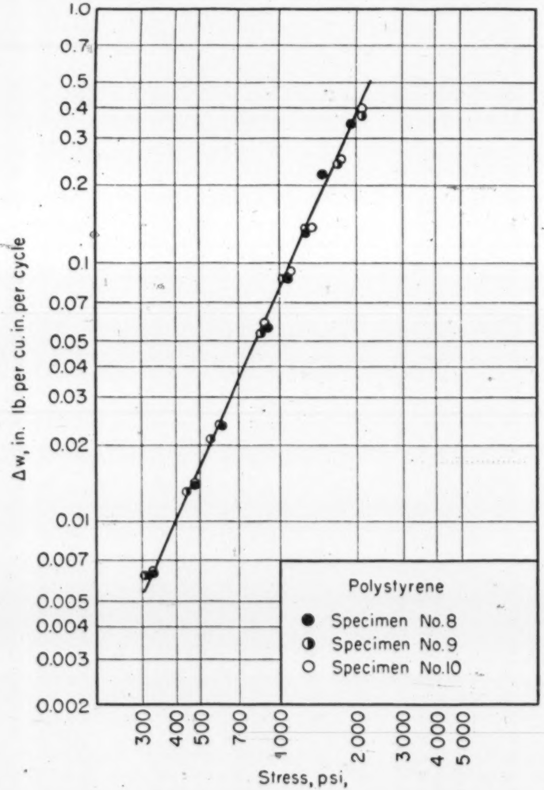

FIG. 3.—Curve of Damping Capacity *versus* Stress.

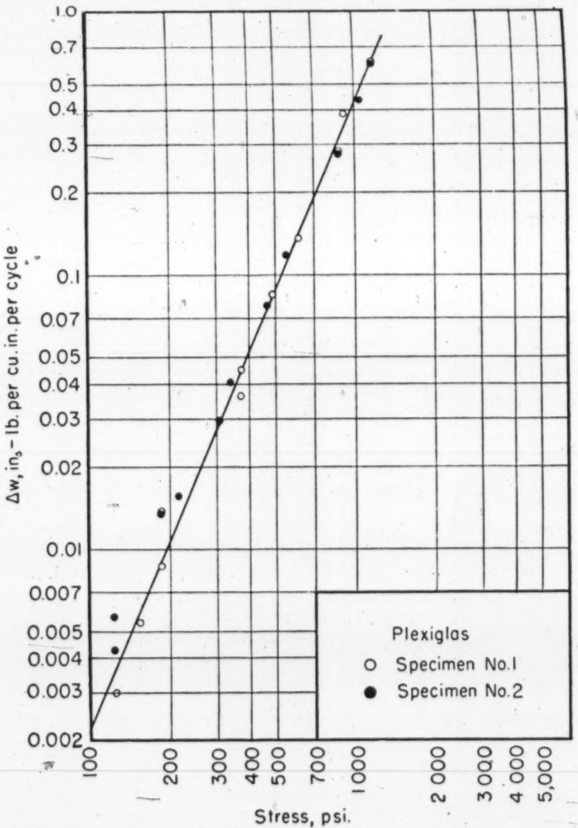

FIG. 4.—Curve of Damping Capacity *versus* Stress.

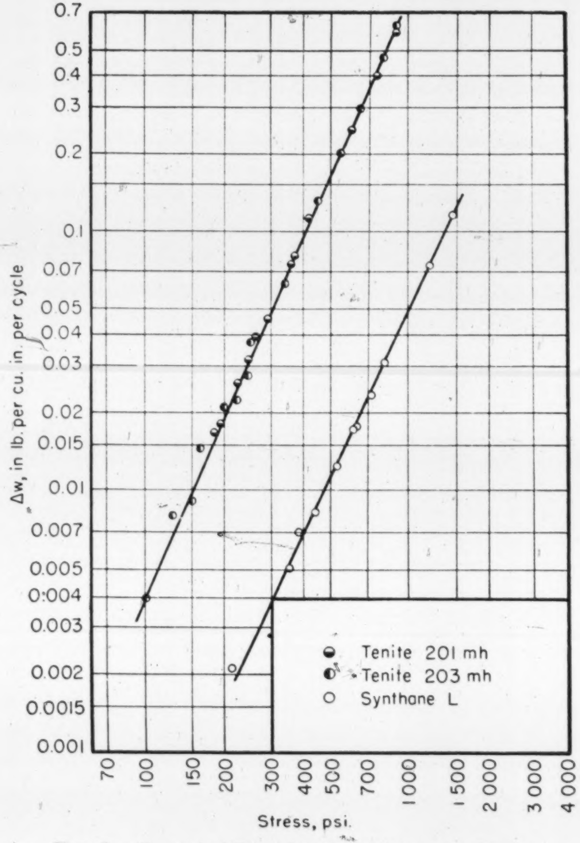

FIG. 5.—Curves of Damping Capacity *versus* Stress.

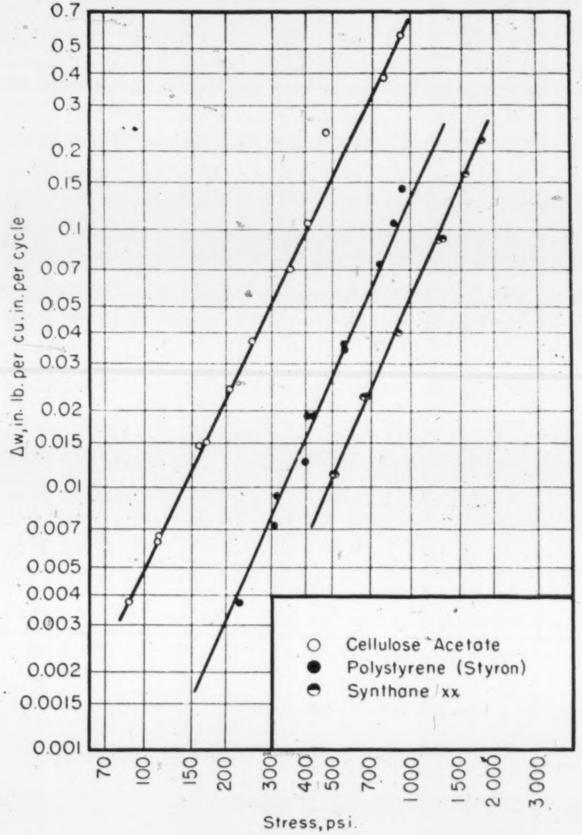

FIG. 6.—Curves of Damping Capacity *versus* Stress.

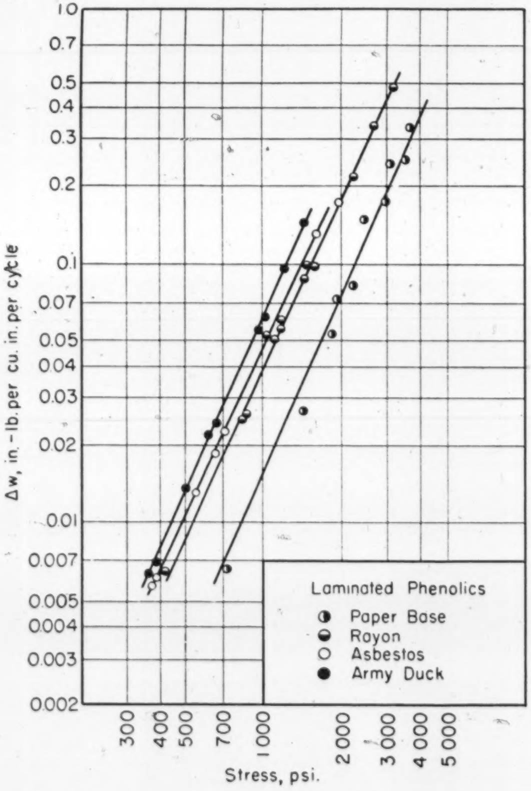

FIG. 7.—Curves of Damping Capacity *versus* Stress.

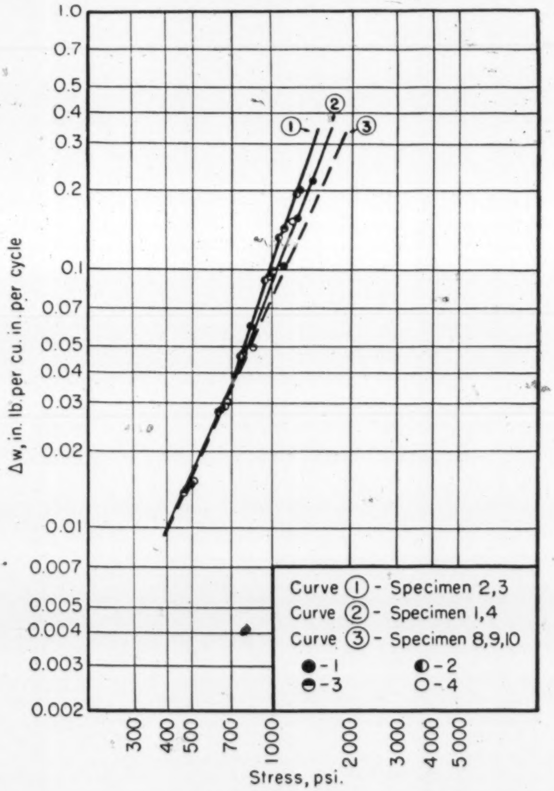

FIG. 8.—Effect of Cracks on Damping-Stress Curves.

relative humidity of 50 ± 2 per cent and a temperature of 77 ± 2 F.

For the other thermoplastic and thermosetting materials tested, no control tests were run and no special conditioning was given to the specimens prior to test. Some of the tests were run on tubular specimens, some on cylindrical specimens, and some on specimens of rectangular cross-section, but all tests were of the alternating tension-compression type (zero mean stress), and all measurements of damping capacity were made at resonant conditions in the manner already described. The dimensions of the various test specimens are given in Table II along with the values of the oscillator frequency.

TEST RESULTS

The measured values of the absorbed energy due to internal friction are plotted against stress amplitude in Fig. 3 for polystyrene (Luxtrex LX), in Fig. 4 for methyl methacrylate (Plexiglas), in Fig. 5 for cellulose acetate butyrate (Tenite 201MH and 203MH) and fabric base phenolic laminate (Synthane L), in Fig. 6 for cellulose acetate (Grade FM6), polystyrene (Styron) and paper-base phenolic laminate (Synthane XX), and in Fig. 7 for four grades of laminated phenolic (high-strength paper base, rayon base, asbestos base, and army duck base). Examination of these log-log plots reveal, first, that the experimental points fall on straight lines and, secondly, the lines are approximately parallel to one another. These features indicate that the absorbed energy can be empirically expressed in terms of the stress amplitude by the equation

$$\Delta W = C\sigma^n \quad \text{..........} (4)$$

where C and n are material constants which can be determined from the data. The constant n is not particularly sensitive to the material under investigation. It takes the value 2.3 for polystyrene (Lustrex LX), and varies only slightly from this value for the other materials whether thermoplastic or thermosetting.

Figure 8 indicates the change in the damping capacity *versus* stress amplitude relation which occurs once fatigue cracks are formed. The dashed line is the same as that in Fig. 3 while the full lines show the results of damping measurements on four polystyrene specimens which had the same cross-section ($\frac{3}{4}$-in. diameter) throughout their length, both within and without the collets, and which were tested without use of a non-metallic filler between the specimen and the collet to reduce the chafing action near the edges of the grip. The results show that at a stress level of approximately 700 psi., there is a noticeable increase in the slope of the damping capacity-stress curve. Evidently, the stress concentration at the edge of the grip produces a suffi-

TABLE III.—COMPARATIVE VALUES OF DAMPING CAPACITY AND DYNAMIC MODULUS FOR SEVERAL THERMOPLASTIC MATERIALS AND SEVERAL THERMOSETTING MATERIALS.

Type of Plastic	Damping Capacity, ΔW, at σ = 500 psi., in lb. per cu. in. per cycle	Exponent of Stress, n, in Eq. 4	Coefficient of Stress, C, in Eq. 4	Dynamic Modulus, E, psi.
THERMOPLASTIC MATERIALS				
Cellulose acetate butyrate (201MH, 203MH)........	0.162	2.30	980 × 10^{-10}	250 000
Cellulose acetate (FM6)........	0.156	2.14	2550	270 000
Methyl methacrylate (Plexiglas)..........	0.0882	2.30	540	610 000
Polystyrene (Styron).......	0.0269	2.32	147	540 000
Polystyrene (Lustrex LX)..	0.0159	2.30	98	530 000
THERMOSETTING PHENOLIC LAMINATES				
Army duck base..	0.0129	2.26	102	1 330 000
Fabric base (Grade L).....	0.0114	2.17	151	1 370 000
Paper base (grade XX)....	0.0108	2.36	50	1 430 000
Asbestos base....	0.0104	2.20	115	1 560 000
Rayon base.....	0.0085	2.20	96	1 720 000
Paper base (high strength)......	0.0324	2.30	19	3 310 000

ciently high local stress to cause crack formation after repeated loading and to indicate this condition by a noticeable increase in slope. Visual examination of each of these specimens after completion of the tests does indeed reveal one or more small cracks in the end section of the specimens near the edge of the collets.

Comparative values of damping capacity, ΔW, and dynamic modulus, E, for the various high polymers tested are given in Table III. The value of E given in this table is only approximate for two reasons, first, because the value varies slightly with stress amplitude (in Lustrex LX from 5.35×10^5 psi. at a stress of 329 psi. to 5.22×10^5 psi. at a stress of 2100 psi.) and, secondly, because the value depends (see Eq. 3) on the value chosen for the specimen length. This is somewhat arbitrary and was taken in this investigation as the measured distance between collets. The data of Table III together with the curves showing absorbed energy *versus* stress amplitude permit us to draw the following conclusions:

1. The damping capacity or absorbed energy per cycle increases with stress amplitude approximately to the 2.3 power (maximum variation is from 2.14 for cellulose acetate to 2.36 for paper-base phenolic laminate). Robertson and Yorgiadis (6) have previously reported a third power variation of damping capacity with stress. Their results were obtained mostly on metal specimens, and only one of their materials (Lucite) might be considered comparable to those tested in this investigation. For this material, their reported test results show such wide scatter that a 2.3 power law would appear to fit their data about as well as a third power law.

2. Although the thermoplastic materials as a group show considerably higher damping capacities than the thermosetting materials, the variation among the different types of thermoplastics is quite large. Among the materials tested, the cellulose acetate butyrate gave the highest energy absorption (approximately ten times that of polystyrene).

3. Among the various phenolic laminates, the variation is not so large. The material showing the highest internal friction value, the army duck laminate, is slightly inferior in this respect to the poorest thermoplastic, polystyrene, but four times higher (at 500 psi.) in energy absorption than the poorest thermosetting material, the high-strength paper-base laminate.

4. In general, as mentioned by Robertson and Yorgiadis (6), materials of lower damping capacity appear to have higher dynamic moduli. Plexiglas is a definite and clear-cut exception to this trend.

5. The damping capacity appears to vary with stress amplitude in the same fashion as the creep rate varies with applied tensile stress. In a preceding paper, Marin and Cuff (2) have reported a linear increase of the log of the creep rate (at 1000 hr.) with log of the applied tensile stress. For polystyrene, their creep rate stress relation is given by $C_r = B\sigma^{4.53}$ where B is an experimental constant. Since, for polystyrene $\Delta W = C\sigma^{2.3}$, the creep rate would appear to vary approximately as the square of the damping capacity. It would thus appear possible to determine 1000-hr. creep rates for polystyrene from measurements of damping capacity. Since creep tests are tedious and time-consuming and since damping capacity tests can be carried out quite rapidly, such a relation might have considerable practical significance.

Resonant Load-Carrying Capacities

From the engineering or design point of view, damping capacity is particularly helpful in reducing stress amplitude when a material is subject to resonant or near resonant vibrations. Under these conditions, energy absorption may be even more significant than endurance strength, and several authors (3, 5, 6) have pointed out that a material of lower fatigue strength but higher damping capacity may well be preferable to another material of higher fatigue strength but lower damping capacity.

It would seem well worth while to attempt to set up a design analysis to take into account both the endurance properties and the damping properties of the various materials. For certain types of members, and certain types of loading conditions, this problem has been treated by Marin and Stulen (7) and also by Yorgiadis and Robertson (8). They consider the magnitude of the resonant load that a given type of member can carry and Marin and Stulen use these resonant load magnitudes to determine relative performance values of both plastics and metals.

There are several objections to the rating which they give. First of all, their assumed values of endurance strength are considerably in error (3000 psi. for lucite, for example, whereas reported experimental values are only 2000 psi.). Secondly, under dynamic loading, each type of material would exhibit a change in modulus and a rise in temperature of a different amount and the relative effect of these changes would be quite variable for the different materials. Thirdly, since the modulus and density of metals and plastics are so markedly different, it is questionable how much significance can be attached to comparative resonant load-carrying capacities, that is load-carrying capacities under widely varying frequencies and widely varying inertial loads due to the vibrating masses.

If we confine ourselves to plastics alone, where the moduli, densities and specific heats, though by no means the same for all types, are nevertheless of comparable magnitude and if we use experimentally reported values of endurance strength, it would seem possible to overcome at least some of the objections listed above. A relative rating of the various plastic materials based on load-carrying ability under resonant vibration might then have more significance than a rating of just damping capacities alone—even though the absolute magnitudes were still based on some questionable assumptions.

Consider a member in the form of a cantilever beam, subject to a dynamic end load oscillating at a frequency equal to the natural frequency of the beam. Assume that the weight of the beam is small compared to the magnitude of the end load, P, so that inertial effects can be neglected, and assume also that the damping due to shear stress can be neglected. The damping due to fiber stress is assumed to vary as the stress to the n power with the value of n as specified in Table III. As has been pointed out by Robertson and Yorgiadis (6), damping capacity may be taken as independent of frequency, at least over the ordinary range of natural mechanical frequencies. Under these conditions, the resonant load P is found to be proportional to the following quantity[4]

$$P \propto C E \sigma_e^{n-1} \ldots\ldots\ldots (5)$$

where C is the damping coefficient of Eq. 4, E the dynamic modulus, and σ_e the fatigue strength. The resonant load-carrying capacity of the beam is thus seen to be a linear function of the damping coefficient and the dynamic modulus and a somewhat higher power function ($\sim$1.3) of the fatigue strength.

Table IV gives values of the resonant

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[4] The analysis is similar to that given in reference (7) except that the variable exponent n is used in place of 3.

load factor, $CE\sigma_e^{n-1}$, for the various polymeric materials whose dynamic moduli and internal friction have been determined in the present investigation. The fatigue strengths of column 5 are rough averages of the reported values (**9**, **10**, **11**, **12**, **13**, and **14**) of comparable material. The value of σ_e for polystyrene (Lustrex LX) was determined experimentally since no reported value for this grade of polystyrene could be found. The fatigue tests were made on a Sonntag machine operating at 1800 rpm. The fatigue test specimens were rectangular in cross-section ($\frac{1}{2}$ by $\frac{1}{2}$ in.) and the tests were made under alternating axial ten-

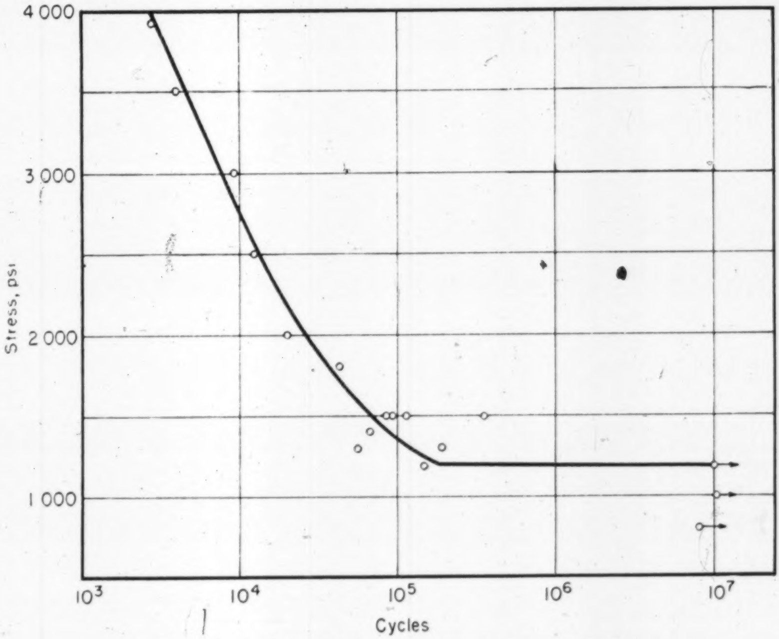

FIG. 9.—*S-N* Curve for Polystyrene (Lustrex LX).

TABLE IV.—RESONANT LOAD RATINGS OF SOME THERMOPLASTIC AND THERMOSETTING MATERIALS

Type of Plastic	Exponent of Stress, *n*, in Eq. 4	*C* ($\Delta W/\sigma^n$)	*C'* ($\Delta W/\sigma^{2.3}$)	Dynamic Modulus, *E*, psi.	Fatigue Strength, σ_e, psi.[a]	Resonant Load Factors	
						$CE\sigma_e^{n-1}$	$C'E\sigma_e^{1.3}$
			THERMOPLASTIC MATERIALS				
Cellulose acetate butyrate (Tenite 201MH, 203MH)	2.30	980×10^{-10}	980×10^{-10}	250 000	....	...	...
Cellulose acetate (FM6)	2.14	2550	965	270 000	1050 (**9, 13**)	190	220
Methyl methacrylate (Plexiglas)	2.30	540	540	610 000	2000 (**9**)	640	640
Polystyrene (Styron)	2.32	147	167	540 000	1500 (**14**)	123	122
Polystyrene (Lustrex LX)	2.30	98	98	530 000	1200	52	52
			THERMOSETTING LAMINATES				
Army duck base	2.26	102	80	1 330 000	....	...	...
Fabric base (grade L)	2.17	151	71	1 370 000	5000 (**9**)	440	620
Paper base (grade XX)	2.36	50	67	1 430 000	5200 (**9**)	730	650
Asbestos base	2.20	115	64	1 560 000	6000 (**10**)	620	810
Rayon base	2.20	96	53	1 720 000	....	...	...
Paper-base (high-strength)	2.30	19	19	3 310 000	7000 (**10, 11, 12**)	640	640

[a] The boldface numbers in parenthesis refer to references at end of paper.

sion and compression loading. Lustrex LX was found to exhibit a quite well-defined fatigue strength (see the *S-N* curve of Fig. 9), a behavior similar to that reported by Findley (14) for an unnamed grade of polystyrene.

Two values of resonant load factors are given in Table IV. The first one is based on Eq. 5 using the *C* and *n* values of Table III. The second one is based on use of a single *n* value of 2.3 for all the materials and a *C* value (marked *C′* in Table IV) obtained from the straight line of constant slope 2.3 used to best fit the data of Figs. 3 to 7. The numerical values of the resonant load factors serve as approximate measures of the relative performance behavior, under resonant conditions, of the different plastic materials.

From the design calculations of Table IV, one may draw the following conclusions:

1. The relative load-carrying capacity of methyl methacrylate under resonant conditions appears to be higher than that for any of the other thermoplastic materials. It is only comparable however to that of the various thermosetting laminates, a conclusion significantly different from that of Marin and Stulen (7), whose analysis indicated laminated phenolic to be greatly inferior to Lucite. The difference is due partly to their use of a cube law for the relation between damping capacity and stress, but mostly to their incorrectly assumed values of endurance strength and dynamic modulus.

2. Among the thermosetting materials, the high-strength paper phenolic laminate has the highest reported endurance limit, but because of lower damping-capacity values shows no better resonant load-carrying ability than the grade XX paper-base or asbestos-base phenolic laminates.

3. The relative rating among the thermoplastic materials undergoes little change whether precise *C* and *n* values are used or whether constant *n* of 2.3 (and appropriate *C′*) is used for all the materials. For the thermosetting materials, the difference is somewhat more significant, but in view of the various assumptions that are involved in the derivation of these expressions, it is questionable whether the difference is sufficient to invalidate the use of a common *n* value and require the use of the experimentally determined *C* and *n* values. More precise measurements of damping capacities are required to settle this point.

The results of Table IV apply only when the material is in the form of a rectangular beam with vibrating end load, but similar calculations can be readily made for other types of member and other types of loading condition. In general, they show a different dependence of *P* on σ_e but the same linear increase with damping coefficient. Whatever the application, the load-carrying ability under repeated loading will depend on both the damping characteristics as well as the fatigue characteristics of the material, and both should be considered in design. Furthermore, strain or deflection calculations under dynamic loading should be based on values of the dynamic modulus and not the static modulus, as the difference in these values is frequently quite appreciable for plastic materials (5.3×10^5 as compared to 4.5×10^5 for polystyrene). Also, if the frequency of oscillation is high and the loading maintained for considerable periods of time, the effect of increased specimen temperature will probably have to be considered.

Acknowledgments:

This investigation has been carried out under the sponsorship and with the financial assistance of the Office of Naval Research. Our thanks are extended to B. L. Black, G. E. Cuff, and S. S. Eckley for technical assistance, and to J. Marin and J. M. Robertson for helpful suggestions. We are indebted also to Howard Adams of the Monsanto Chemical Co. for supplying us with the molded polystyrene sheets.

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(14) W. N. Findley, "New Apparatus for Axial-Load Fatigue Testing," ASTM BULLETIN, No. 147, August, 1947, p. 54.

DISCUSSION

Mr. A. J. Warner.[1]—I believe I am correct in assuming that these measurements were all made at constant ambient temperature.

I wonder if any experiments have been made with different temperatures and whether there are any different slopes of the characteristics with temperature for the materials under investigation.

Member.—Was there any attempt made to check this damping capacity against the hysteresis loop for these various materials? Mr. Marin showed hysteresis loops, for static tension tests of these same thermosetting materials, in a report several years ago to the National Advisory Committee of Aeronautics.

Mr. W. N. Findley[2] (*by letter*).—The authors have presented excellent data on damping capacity, some interesting speculations on the correlation between damping and creep rate, and a load-factor for evaluating the relative merits of different materials for resisting resonant vibration.

Interpretation of Dynamic Measurements:

In view of the excellence of the test data on damping as evidenced by the freedom from scatter, it seems appropriate to examine further the implications of these results as related to the test method and method of analysis employed, even though the method and analysis has been widely used to study the dynamic properties of many materials.

The equations used by the authors were derived from the motion and forces present in resonant vibration of a single-degree-of-freedom system consisting of masses, linear spring, viscous damping and sinusoidal excitation. The differential equation for such a system is of the form[3]

$$M\ddot{x} + c\dot{x} + kx = F \sin \omega t \quad (6)$$

where x, $\dot{x}$ and $\ddot{x}$ are the displacement, velocity and acceleration respectively, c is the viscous damping coefficient, k is the stiffness of the spring, and the other symbols correspond to those in the paper.

From the solution of this differential equation it is possible to calculate the energy dissipated per cycle, W_D, by the viscous damping.[4] The relationship obtained is

$$W_D = \pi c a^2 \omega \quad (7)$$

For the mechanical system described above, this dissipated energy is equal to the work done per cycle by the disturbing force F as calculated by the authors from their Eq. 1.

Equation 7 indicates that the energy dissipated per cycle by the damping is proportional to the square of the amplitude of the motion. If the stress, σ in the specimen is understood to be defined in terms of the spring force alone (which is the only force acting in the specimen at the maximum displacement) and the spring force is linear as required in this solution, then the stress is proportional to the amplitude so that Eq. 7 becomes

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[1] Technical Director, Chemical and Physical Labs., Federal Telecommunication Laboratories, Inc., Nutley, N. J.

[2] Research Associate Professor of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

[3] Timoshenko, "Vibration Problems in Engineering," Second Edition, D. Van Nostrand, p. 38 (1937).

[4] *Ibid*, p. 45.

$$\left.\begin{aligned} W_D &\propto c\,\sigma^2\,\omega \\ \text{or}\quad W_D &= C\,\sigma^2 \end{aligned}\right\}\ldots\ldots\ldots(8)$$

where C includes the viscous damping constant the dimensions and stiffness of the specimen, and the frequency of the vibration.

That the tests reported by the authors showed the work done per cycle by the disturbing force (oscillator) to be proportional to the 2.3 power of stress may indicate that polystyrene behaves as a viscous material as regards damping. The fact that the 2.3 power was found instead of the 2.0 power may be a manifestation of the use of an equation for a system with a single viscous element, Eq. 6, to represent the behavior of a viscous material having a distribution of viscosities or relaxation times such as polystyrene is considered to have.

On the other hand it seems equally possible to the writer that the 2.3 power may result from some part of the mechanical equipment used by the authors not performing in accordance with the linear relationship required by the procedure used to calculate the damping capacity.

Further evidence that the test equipment may not function in the linear manner described by the differential Eq. 6 are found in the facts that: (*a*) the so-called dynamic modulus calculated from the vibration test (5.3×10^5 psi.) differs from the static modulus (4.5×10^5 psi.) and in the opposite direction from that reported by previous investigators[5] using the same apparatus in tests of other plastics, and (*b*) the dynamic modulus changed with stress. Neither of these observations is in accord with the conditions described by the differential equation which requires the dynamic modulus to be constant and equal the static modulus.

Some of the possible sources of this disagreement may be: (*a*) the stiffness of the specimen changes with displacement, (*b*) the stiffness of the specimen changes with strain rate (or frequency), (*c*) the oscillator may not provide the required pure sine wave of disturbing force, (*d*) the damping in the specimen may not be viscous, and (*e*) there may be energy dissipated in non-linear friction in the grips or other parts of the vibrating assembly.

The only one of these possibilities which seems to be easily evaluated from the available data for polystyrene is the first. Since the slow speed tension tests show a linear relation between stress and strain practically to fracture (about 5500 psi.) and the largest stresses used for damping were only 2100 psi. it seems improbable that the stiffness changes with displacement during the vibration.

It is possible that the modulus may increase slightly with increase in strain rate if the increase in strain rate overlaps a portion of the spectrum of relaxation times for the material. It seems unlikely, however, that this would explain the large change in stiffness observed. It is perhaps more likely that the damping is not viscous.

An extensive study of many of the possible sources of extraneous energy dissipation in one type of damping testing machine has recently been reported.[6] These investigators found external losses of energy amounted to as much as 500 times the intrinsic energy dissipation of aluminum alloy specimens.

A mathematical expression which would be more suitable for representing hysteresis damping is evidently needed. The following expression which has been considered for damping in structures[7] might prove useful in the present instance:

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[5] B. J. Lazan and A. Yorgiadis, "The Behavior of Plastic Materials Under Repeated Stress," Symposium on Plastics, Am. Soc. Testing Mats., p. 66 (1944). (Symposium issued as separate publication, *STP No. 59.*); B. J. Lazan, "Some Mechanical Properties of Plastics and Metals Under Sustained Vibrations," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 65, p. 87 (1943).

J. M. Robertson and A. Yorgiadis, "Internal Friction in Engineering Materials," *Transactions*, Am. Soc. Mechanical Engrs., *Journal Applied Mechanics*, Vol. 68, p. A-173 (1946).

[6] G. A. Cottell, K. M. Entwistle, and F. C. Thompson, "The Measurement of the Damping Capacity of Metals in Torsional Vibration," *Journal*, Inst. Metals, March, 1948, p. 373.

[7] N. O. Myklestad, "Vibration Analysis," 2nd Ed. McGraw-Hill, Book Co., New York, N. Y., Sec. IV-5 (in preparation).

$$M\ddot{x} + k(\cos b_1 + i \sin b_1)x = Fe^{i\omega t} \quad \ldots (9)$$

The damping in this equation is called complex damping and is represented in the equation by the phase angle of lag b_1.

A study of the solution of this equation shows that the damping capacity (energy absorbed per unit volume per cycle for a uniform rod vibrating axially) is proportional to the sine of the damping constant, b_1, the square of the stress, inversely proportional to the elastic modulus and independent of the frequency. The last three of these relationships are in accord with much of the reported data on damping capacity in materials: (*a*) Kimball and Lovell[8] found the damping capacity to be proportional to the square of the stress for a number of different materials, (*b*) they also gave rather conclusive evidence that the damping capacity is independent of frequency (or velocity) and (*c*) as mentioned by the authors the data on damping capacity reported in the literature indicates that in general materials with the highest elastic moduli have the lowest damping capacity and *vice versa*. No exact relationship can be shown because of the fact that many of the damping capacities reported are for different stresses and the damping constants (such as b_1) are probably different.

A comparison of the damping capacity described above for complex damping with that predicted for viscous damping shows that the viscous damping capacity calculated from Eq. 7 or the authors Eq. 1 cannot be expressed (in terms of energy per unit volume) as a function of stress and factors which are properties of the unit volume of the material alone. Other quantities which depend on the particular configuration, such as the mass of the vibrating body and dimensions of the specimen tested, cannot be eliminated from the expression. Also the viscous damping capacity is not a function of the modulus of elasticity and is a function of frequency—the reverse of the relationship for complex damping.

Correlation of Damping Capacity and Creep Rate:

It seems quite likely that damping and creep (also fatigue for that matter) are different responses to the same action at the atomic or molecular level of action in a material. Thus it would be likely that equations derived from the atomic or molecular behavior to describe these three different responses to mechanical loading would have at least one factor in common.

It would indeed be very useful if creep could be predicted from damping measurements. If such a correlation is to be useful for engineering applications it must be more than a chance correlation. It must be based on correspondence of fundamental physical behavior of the material under the two conditions. That such a condition exists in the present instance seems doubtful to the writer though he wished it were otherwise.

The following observations may be of interest in trying to evaluate this possibility. As discussed above the damping capacity varies with the stress to the second power for viscous damping. Viscous creep rate on the other hand has been described as varying linearly with the stress.[9] This is a considerable difference from the relation found by the authors (a 2.3 power of stress for damping and 4.53 power of stress for creep rate).

The failure of the data for styrene to follow the same stress laws predicted for viscous behavior for both damping and creep does not seem too unreasonable in view of the differences in amount of strain and strain rate in the two phenomena. The behavior may result from quite different mechanisms, for example, rupture of secondary bonds between atoms in damping and movement during creep of groups of molecules of large molecular weight in a matrix of molecules of smaller molecular weight.

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[8] A. L. Kimball and D. E. Lovell, "Internal Friction in Solids," *Physical Review*, second series, Vol. 30, pp. 947–959 (1927).

[9] Schmidt and Marlies, "Principles of High-Polymer Theory and Practices," McGraw-Hill, Book Co., New York, N. Y., Chapter 7 (1948).

Dimensional considerations also suggest that equations such as $W_{\mathrm{D}} = c\sigma^{2.3}$ and $v = B\sigma^{4.53}$ are unlikely to be more than approximations of the actual physical relation between the quantities since a dimensional quantity raised to a variable or unfactorable fraction power is dimensionally untenable. As an approximate or empirical expression the dimensions may be satisfied by the trick of introducing a constant (such as unity) having suitably variable dimensions but such tricks are thought to have no physical significance.

Even though it should be shown that creep and damping are different manifestations of the same atomic behavior it seems doubtful that creep could ever be completely predicted from damping measurements. The phenomena, resulting possibly from the same atomic behavior, are quite different for creep than for damping. Thus in fundamental equations for these two phenomena one or more significant factors must be expected that are not common to both equations.

Another fact which perhaps should be mentioned in this connection is that creep rates from tests which the writer has performed on a polystyrene[10] obtained from the same manufacture, and having about the same molecular weight of 68,000 (Staudinger), agree reasonably well with the results presented by Marin and Cuff[11] for the stress values which were common to the two tests.[12] However, when the writer's data are plotted with the log creep rate *versus* the log stress the resulting line shows a marked curvature. The writer's data fit a hyperbolic sine function better than a power function. The authors may find that their data can also be represented by an hyperbolic sine function or an exponential function nearly as well as by a power function. The hyperbolic sine function has the advantage to the present discussion of being related to the activation energy theory of the mechanism of creep and hence being more likely to have physical significance than the other functions.

Resonant Load Factors:

The authors have discussed some of the dangers in the use of a resonant load factor when comparing plastics and metals for resistance to failure from resonant vibration. The writer feels that the use of such factors of merit may usually be attended by some danger of incorrectly rating materials for some applications or of omitting significant characteristics. In the present instance the serviceability of a material for use in applications where resonant vibration cannot be avoided may depend either on the amplitude of vibration remaining less than a given value or on the stress remaining below the fatigue strength for the operating temperature, etc.

If control of the amplitude of vibration is required the fatigue strength is unimportant so long as it is high enough that failure will not occur at the specified amplitude. Thus a factor of merit which included the fatigue strength would give an undue advantage to materials having fatigue strengths higher than required.

The ability of plastics to perform satisfactorily in resonant vibration will depend on the temperature developed by the damping since the stiffness, fatigue strength and probably damping capacity change with temperature. The temperature in turn will depend not only on the energy dissipated per cycle but the frequency, duration of time of the vibration and the means for heat transfer in the given situation. Thus the thermal conductivity of the material is an important characteristic in determining the resistance of plastics to failure from resonant vibration.

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[10] Unpublished.

[11] J. Marin and G. E. Cuff, "Creep-Time Relations for Polystyrene Under Tension, Bending, and Torsion," see p. 1158 of this publication.

[12] *Ibid*, Discussion, p. 1175.

In view of the above the problem seems so complex and the relative importance of the various factors seems to vary so with different applications that the use of a single figure of merit might be misleading. It seems that it might be safer or at least more accurate to consider each pertinent characteristic of the material in the setting of the given problem when selecting a plastic for an application involving resonant vibration.

Also in any given structure the contribution of air damping and friction in joints must be considered if an accurate prediction of performance under resonant conditions is to be expected.

MESSRS. J. A. SAUER AND W. J. OLIPHANT (*authors' closure*).—The question has been raised as to whether any attempt was made to correlate the damping capacity determined in this investigation with hysteresis loop measurements made by Marin[13] on some comparable materials. Three of the materials used in this investigation, namely, the high-strength paper base phenolic laminate, the rayon base laminate, and the Army duck laminate, were also used by Marin. However, the measurements of hysteresis loops which he made were for slow-speed static tension tests and were carried out at stresses of two-thirds of the static ultimate strength. These stresses were 6130 psi. for the Army duck laminate, 16,500 psi. for the rayon base laminate, and 16,800 psi. for the paper-base laminate. These stresses are so very much higher than the stresses used in the present investigation, which were of the order of 1000 to 3000 psi., that it would not be permissible to extrapolate the damping-stress relation reported in the present paper. It might, however, be pointed out that the relative rating of these three materials, in so far as energy absorption at a given stress is concerned, is the same for both investigations.

Mr. Warner asks about the effect of temperature on the slopes of the damping capacity *versus* stress curves. No direct information on this point is available as the damping capacity tests were conducted at but one ambient temperature (approximately 77 F.). The specimen temperature during test was, of course, several degrees higher than the surrounding atmosphere due to the absorption of energy through internal friction. The increase of specimen temperature over surrounding atmospheric temperature was kept as small as possible by running the tests rapidly and by allowing the specimen to cool between runs. Even at the highest stresses for which damping capacity data were taken, it is doubtful if the specimen temperature exceeded 85 F. Evidently, the amount of heating which did take place had no important effect on the properties of the material, as a rerun of tests at low stress values after completion of the tests at higher stress values showed no appreciable differences in damping capacity values.

The authors wish to express their appreciation to Mr. Findley for the interest he has taken in this paper and for the various comments he has made. However, it should be made clear, first of all, that the method used in our paper does *not* assume that damping is viscous as Findley states in several places in his discussion. Furthermore, our Eqs. 1, 2, and 3 were *not* derived from considerations of the viscous damping case.

The derivations of these equations were not given in the paper as they have already appeared in the literature.[14] As pointed out by Lazan,[14] they are more general than the equations obtained for the case of viscous damping and depend only on the condition that the force and the resulting displacement are sinusoidal. This condition may well occur, as a first approximation, for systems whose behavior is much more complex than that represented by Eq. 6. It is also known to be experimentally satisfied as the oscillator force is definitely sinusoidal as long as the frequency is constant, and Lazan found that the actual displacement was also essentially sinusoidal. The damping capacity determined by Eq. 1 is a measure of the energy absorbed due to the non-coincidence of the upward and downward portion of the stress-strain curve. It is this energy which was experimentally found to vary with the stress to the 2.3 power.

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[13] J. Marin, "Static and Dynamic Creep Properties of Laminated Plastics for Various Types of Stress," *Technical Note 1105*, N.A.C.A., February, 1947.

[14] B. J. Lazan, "Some Mechanical Properties of Plastics and Metals Under Sustained Vibrations," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 65, p. 87 (1943).

The fact that truly viscous damping leads to an energy per cycle proportional to the stress to the 2.0 power means only that hysteresis damping of polystyrene specimens subject to oscillating tension-compression loads is not the same as viscous damping. There need be nothing perturbing about this fact, as there is no *a priori* reason to expect that the damping would be viscous.

Since Findley's Eq. 6 is not a representation of the actual system, the dynamic modulus and static modulus need not be equal. There are many reasons for a difference to exist, and these have been pointed out previously by Lazan.[14] One important one, in so far as our tests on polystyrene are concerned, is the very large difference in rate of straining in the slow-speed static tests and the very high-speed dynamic test. This difference in rate of straining is sufficiently great to produce a significant increase of dynamic modulus over static modulus. A separate study of the effect of rate of strain on the stress-strain properties of polystyrene is now under way, and specific results will be reported soon in the literature.

It is suggested in Findley's discussion that hysteresis damping can be treated mathematically by the introduction of so-called complex damping, such as has been considered for use in structures. It is difficult, however, to see the physical significance of this type of damping, especially when it appears as in Eq. 9 in the form of a complex spring constant. A more reasonable approach to the problem might be to assume a damping force proportional to some power of the velocity other than one and then solve the resulting differential equation by approximate methods. Perhaps in this manner one could obtain an analytical expression for the damping capacity in agreement with the experimental results.

In so far as the relation between creep and damping is concerned, our paper simply pointed out that both creep rate and damping capacity were found over the range of stresses investigated—to be proportional to a power function of the stress. This being so, elimination of stress between the two equations would enable one to express 1000 hr. creep rates for polystyrene in terms of damping capacity values. Findley's objection to this correlation seems to be based on the fact that for viscous damping, damping capacity varies with stress to the 2.0 power and for viscous creep, creep rate varies linearly with stress, and hence the relation between viscous damping and viscous creep is considerably different than the reported relation between hysteresis damping and actual creep rate. However, it has already been pointed out that internal damping in polystyrene is not viscous; also it is inconceivable that flow in solid polystyrene at room temperatures would be even approximately Newtonian. As a matter of fact, even well above its second-order transition temperature, where one might reasonably expect its behavior to be more like that of a Newtonian viscous liquid, polystyrene is found to have non-Newtonian flow properties.[15]

In his discussion, Findley states that creep rates obtained from creep tests run in his laboratory on somewhat similar polystyrene specimens "agree reasonably well with the results presented by Marin and Cuff" for comparable stress values. In view of this correlation, it seems unwise to state that the reported relations between creep rate and stress and between damping capacity and stress are not correct because they offend "dimensional" sensibilities. As Bridgeman[16] has stated, "In the face of a fact, there is only one possible course of action for the scientist, namely, acceptance, no matter how much the fact may be at variance with his anticipations and no matter what havoc it may wreck on his carefully thought-out theories."

It is also difficult to see why these relations are "dimensionally untenable." For example, does not a similar situation exist in the accepted isentropic equation of state for a perfect gas, namely, PV^{γ} = constant, where P is the pressure, V the specific volume, and γ the ratio of specific heat at constant pressure to the specific heat at constant volume? For air at ordinary temperature $\gamma = 1.4$, thus leaving the constant with very peculiar dimensions. Just as this last equation is frequently written in the form of dimensionless quantities, that is, $\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^{1.4}$, so could the damping capacity - stress relation or the creep rate - stress relation. For example, let C of Eq. 4 equal the ratio of some unit of energy, W_o, to some unit of stress S_o. The damping capacity - stress relation then becomes $\frac{\Delta W}{W_o} = \left(\frac{S}{S_o}\right)^n$ and both sides are expressed in dimensionless form.

In connection with the interpretation of resonant load capacity, the authors clearly pointed out that the use of this concept necessitated the making of a number of assumptions. One such assumption was neglect of the effect of thermal conductivity. Since our particular interest was to show the combined interlocking effects of damping and fatigue resistance and since the thermal conductivities of the materials tested were of comparable order of magnitude, it was not felt that the omission was serious. Findley also discusses an example in which the fatigue strength is unimportant, "so long as it is high enough that failure will not occur at the subjected amplitude." Does this not mean that the fatigue strength must be considered and, if maximum load is desired, will not fatigue strength and damping be important?

Because the problem is complex is no reason for not attempting it, as Findley seems to suggest. Many scientific and engineering problems are of necessity complex, and it is only by making suitable simplifying assumptions, such as the authors attempted to do in this paper, that the problem can be treated. Even though all of these assumptions may not hold, it seems worth while to point out the conclusions that follow and in this way to treat at least some definite problem in an analytic fashion. Later on, additional refinements can be made so that eventually one should be able to treat analytically all the variables which enter into a given setup. Such a procedure seems more appropriate to the authors than a simple tabulation of the characteristics of the material in question.

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[15] R. Buchdahl, "Rheology of Thermoplastic Materials, I. Polystyrene," *Journal of Colloid Science*, Vol. 3, No. 2, May, 1948.

[16] P. W. Bridgeman, Talk given at the Mid-Century Convocation of the Massachusetts Institute of Technology, March 31–April 2, 1949.

THE CREEP CHARACTERISTICS OF COMPRESSION MOLDED POLYETHYLENE*

BY G. R. GOHN,[1] J. D. CUMMINGS,[1] AND W. C. ELLIS[1]

SYNOPSIS

This paper describes studies made to determine the creep characteristics of compression molded polyethylene and polyethylene compounds similar to those now being used in the manufacture of the composite cable sheath known as "Alpeth." The compounds contain carbon black and an anti-oxidant which were added to minimize deterioration by sunlight and the elements. Data, some of which cover a period of nearly three years, are presented to show the creep properties of these organic materials at various stress levels ranging from 50 to 1000 psi. The effect of shelf aging and artificial weathering on the creep of polyethylene and polyethylene compounds is also indicated.

For the past sixty years, the conventional sheath for communication and power cables has been extruded from lead or lead alloys. Because of the periodic shortages of lead which have occurred since the first World War, studies were initiated to develop other types of sheath. As a result of these studies, a new sheath has been developed by the Bell Telephone Laboratories and the Western Electric Co. which is now being made for Bell System use at both the Kearny and the Hawthorne plants of the latter organization. This sheath (Fig. 1), consisting of a composite covering of corrugated aluminum, water-resistant compounds and an outer coating of polyethylene, has been termed Alpeth, a name coined from the two words, *al*uminum and *p*oly*eth*ylene (**1, 2**)[2]. The polyethylene contains carbon black and an anti-oxidant, added to minimize deterioration of such an organic compound when exposed to sunlight and the elements.

Properties of cable sheathing materials of interest to the designer include a knowledge of the stability of the material, wear and abrasion resistance, fatigue strength, and creep characteristics. This paper deals with a study of the creep characteristics which are also related to stress relaxation and fatigue. The present authors are not aware of any reported information on the creep properties of polyethylene.

MATERIAL INVESTIGATED

The materials studied in this investigation were all compression molded sheet stock having a nominal thickness of 0.125 in. and made with or without the addition of antioxidants and carbon black. They are designated:

Lot A.—Clear, molded by Western Felt Works from raw material obtained from supplier M. This lot, which contained no carbon black or antioxidant, was tested "as received" and also after shelf aging.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] Member of Technical Staff, Bell Telephone Laboratories, Inc., New York, N. Y.

[2] The boldface numbers in parenthesis refer to the list of references appended to this paper, see p. 1151.

Lot B.—Black, molded by Bell Telephone Laboratories from compound obtained from supplier M. This compound contained 1 per cent carbon black and 0.2 per cent antioxidant.

Lot C.—Black, molded by Bell Telephone Laboratories from compound obtained from supplier N. This compound contained 1 per cent carbon black and 0.2 per cent antioxidant. Lot C was tested "as molded" and also after shelf aging.

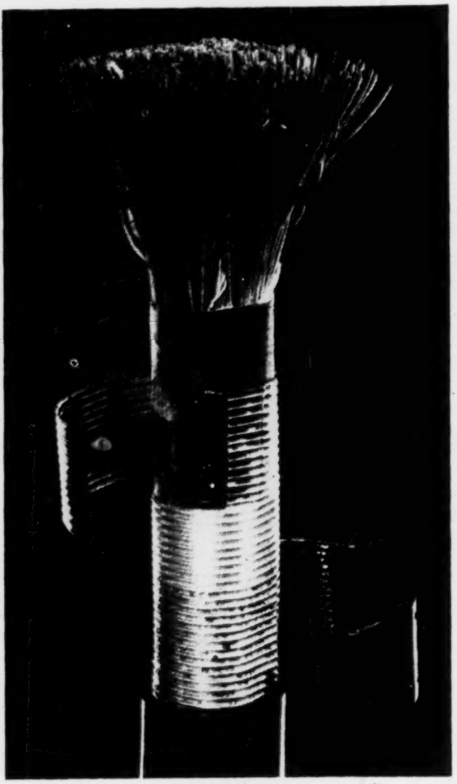

Fig. 1.—Dissected Alpeth Cable.

Lot D.—Black, molded by Bell Telephone Laboratories from compound obtained from supplier M. This compound contained 2 per cent carbon black and 0.2 per cent antioxidant. Lot D was tested after shelf aging and also after artificial aging.

METHODS OF TEST AND TEST DATA

The creep characteristics of the compression molded polyethylene sheet were determined on specimens cross milled to the dimensions shown in Fig. 2. This specimen is similar to the standard 2-in. gage length tension test specimen shown in Fig. 2 of A.S.T.M. Standard Methods of Tension Testing of Metallic Materials (E 8 – 46)[3] except that for all lots but A, a 3-in. gage length was used. The creep tests were made by hanging the test specimens on specially designed racks, which have been previously described by Gohn, Arnold, and Bouton (3). All loads were applied directly as shown in Fig. 3 of that paper (3) and the tests were made at 85 F. The extension was determined in the manner previously described (3) for specimens of lead cable sheath using scribed bench marks to define the gage length. The cathetometer readings had a precision of ±0.1 per cent for the 2-in. gage lengths

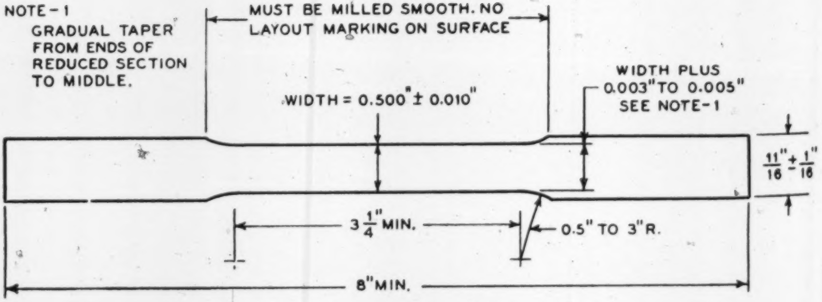
NOTE-1
GRADUAL TAPER FROM ENDS OF REDUCED SECTION TO MIDDLE.
MUST BE MILLED SMOOTH. NO LAYOUT MARKING ON SURFACE
WIDTH = 0.500" ± 0.010"
WIDTH PLUS 0.003" TO 0.005" SEE NOTE-1
11"/16 ± 1"/16
3 1/4" MIN.
0.5" TO 3" R.
8" MIN.

Fig. 2.—Creep Test Specimen.

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[3] 1946 Book of A.S.T.M. Standards, Part I-A, p. 698.

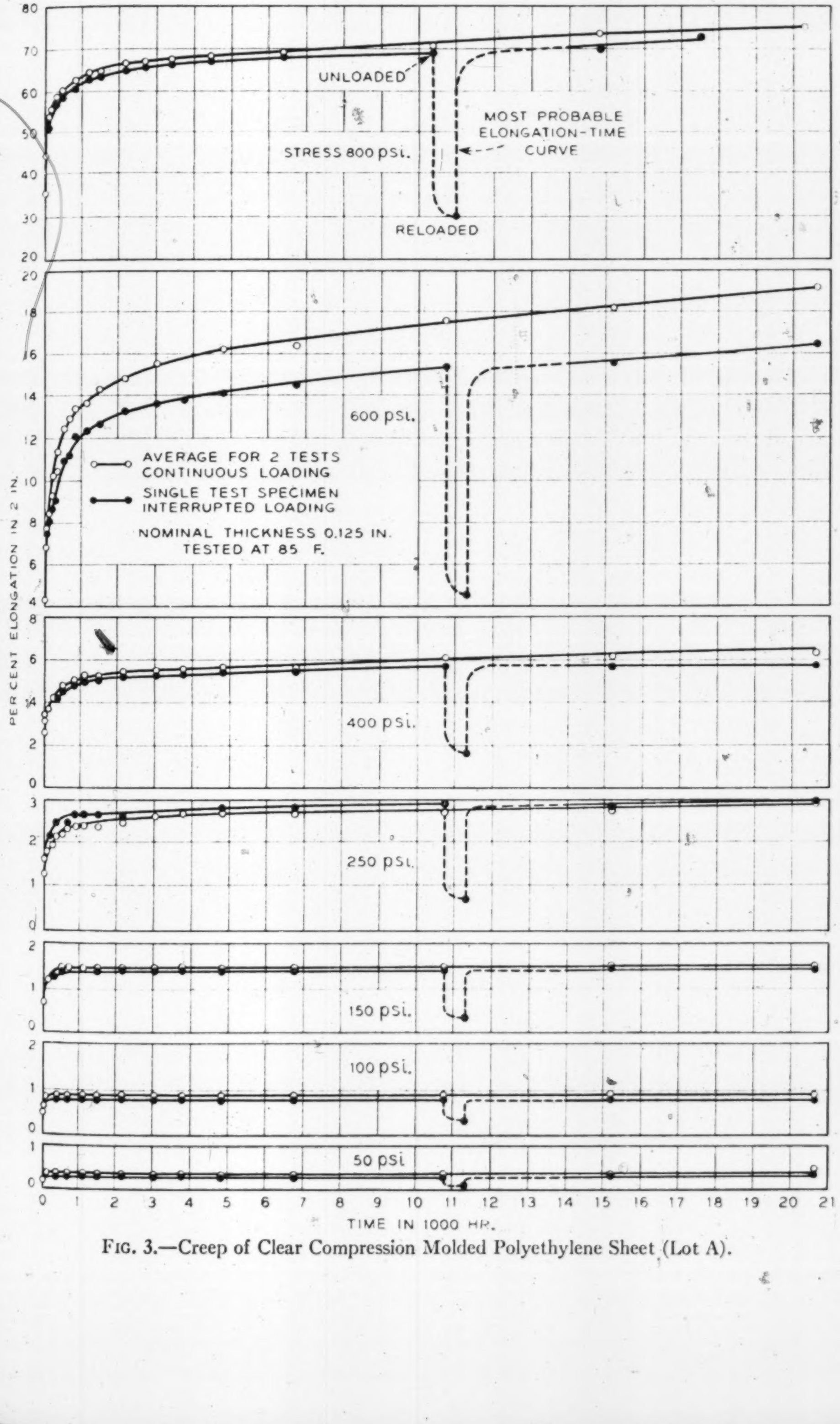
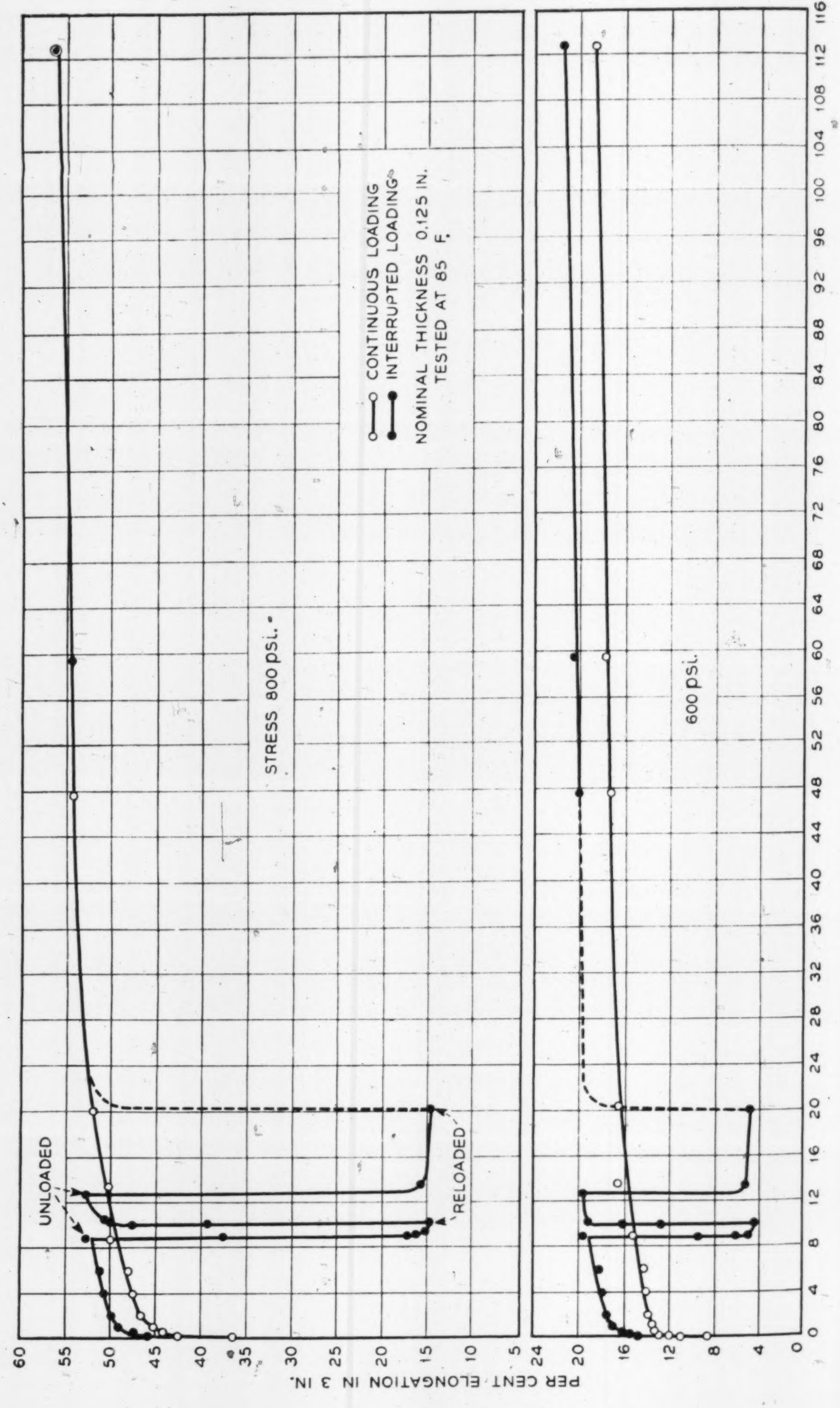


FIG. 3.—Creep of Clear Compression Molded Polyethylene Sheet (Lot A).


CONTINUOUS LOADING
INTERRUPTED LOADING
NOMINAL THICKNESS 0.125 IN.
TESTED AT 85 F.
STRESS 800 psi.
600 psi.
UNLOADED
RELOADED
PER CENT ELONGATION IN 3 IN.
60
55
50
45
40
35
30
25
20
15
10
5
24
20
16
12
8
4
0
0
4
8
12
16
20
24
28
32
36
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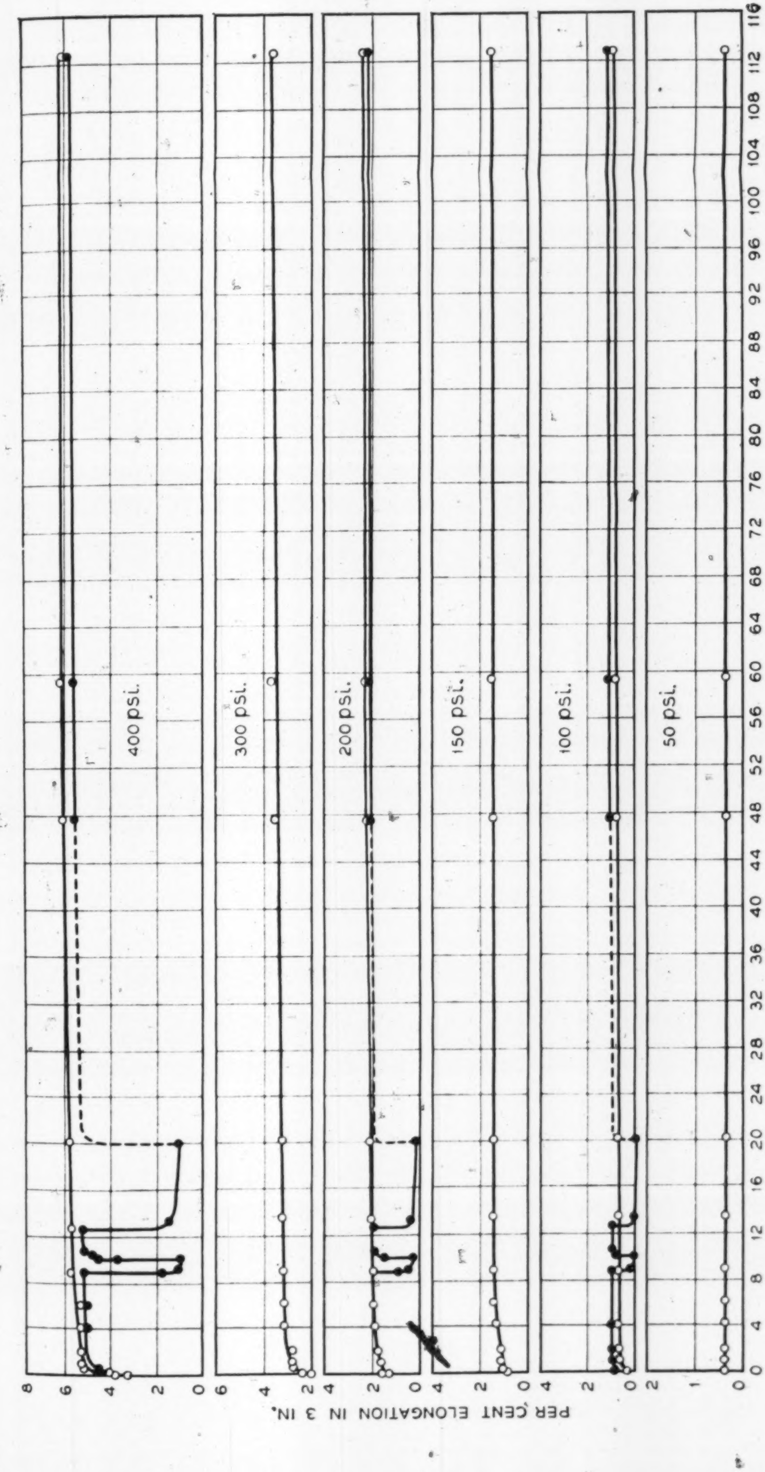

FIG. 4.—Creep of Compression Molded Polyethylene Sheet Containing 1 per cent Carbon Black and 0.2 per cent Antioxidant (Lot B).

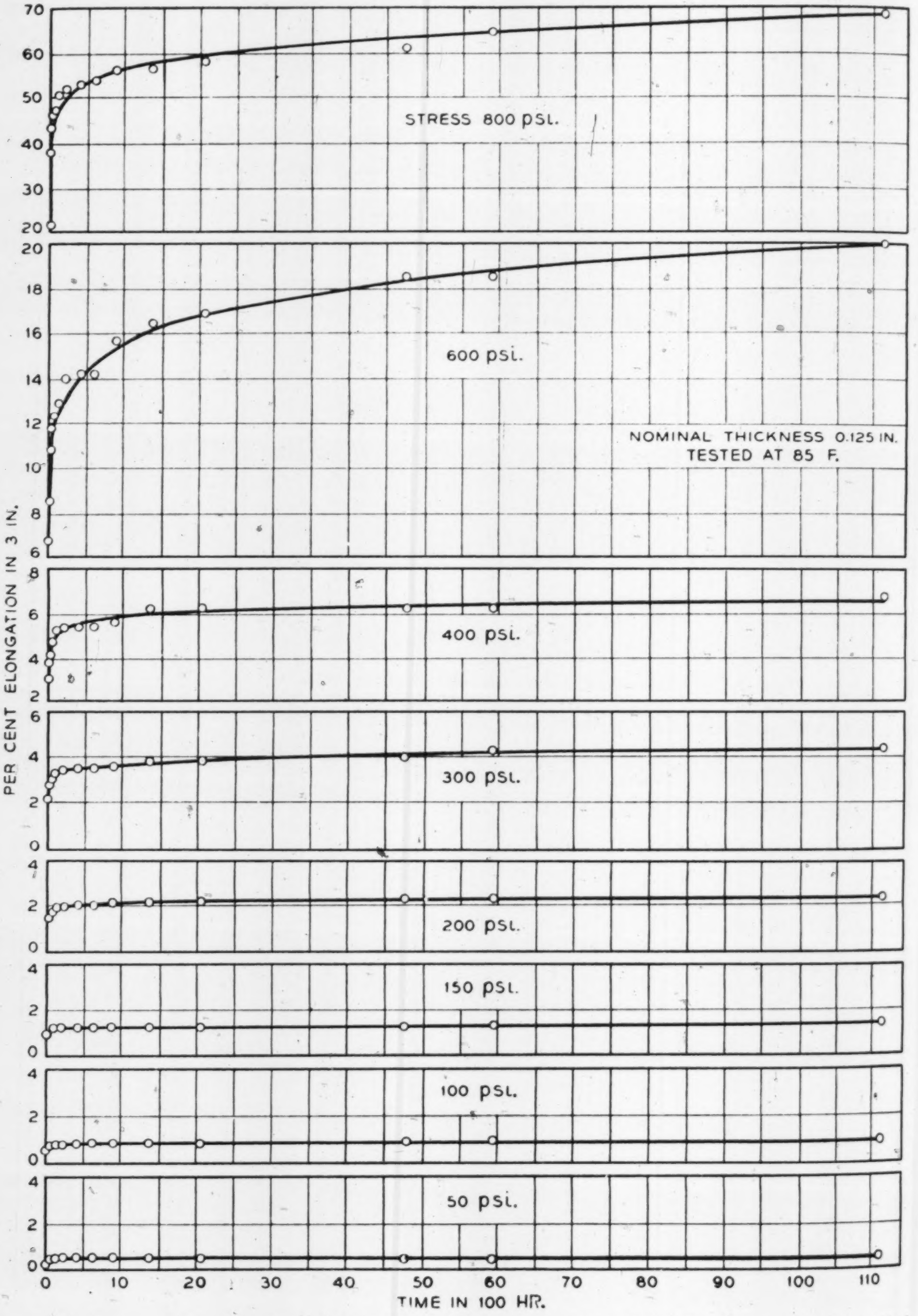

FIG. 5.—Creep of Compression Molded Ployethylene Sheet Containing 1 per cent Carbon Black and 0.2 per cent Antioxidant (Lot C).

and ±0.07 per cent for the 3-in. gage lengths.

Figures 3, 4, and 5 contain elongation-time data for lots A, B, and C, respectively, tested at a series of stresses ranging from 50 to 800 psi. The curves plotted with hollow circles represent the average of two specimens. In Figs. 3 and 4 the curves plotted with solid circles show the effect of unload-reload cycles. In these tests, only a single specimen was used at each stress.

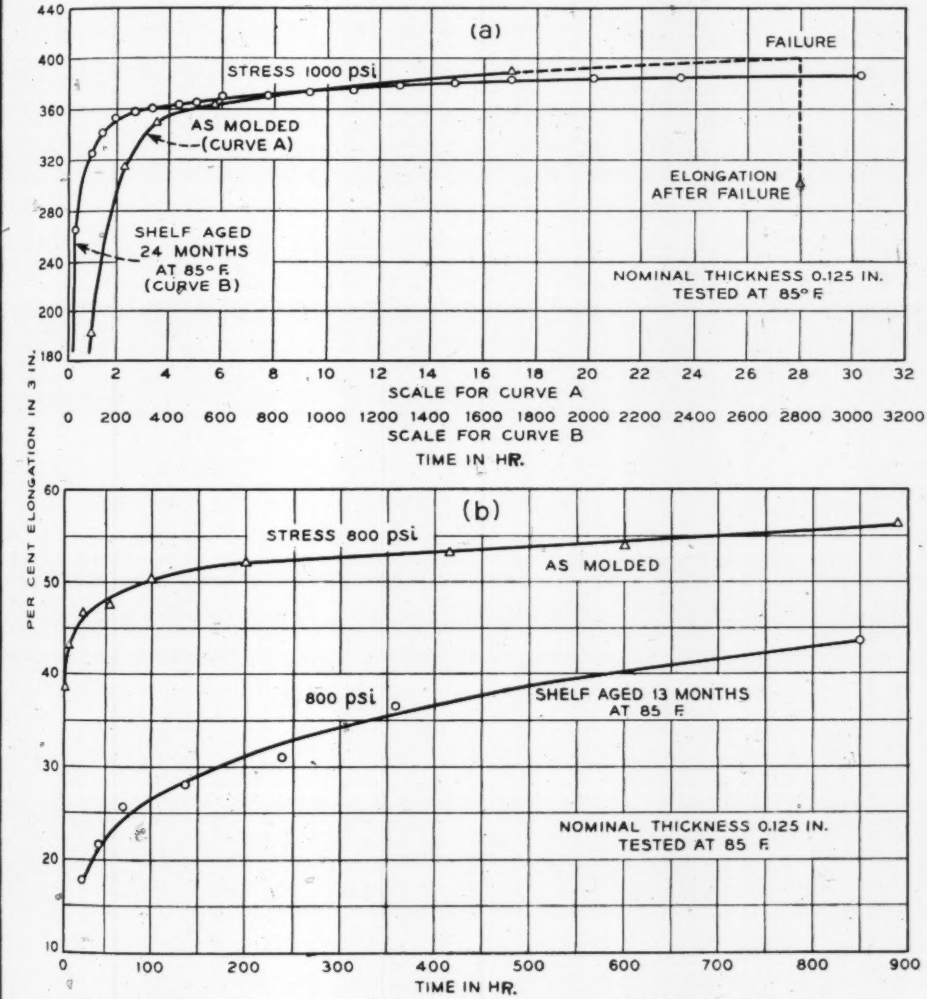

FIG. 6.—Effect of Shelf Aging on Creep of Compression Molded Polyethylene Sheet.
(*a*) Clear Sheet (Lot A).
(*b*) Sheet Containing 1 per cent Carbon Black and 0.2 per cent Antioxidant (Lot C).

Figures 6 and 7 show the effect of shelf aging and artificial weathering on the creep characteristics for lots A, C, and D. The data are, in most instances, averages for two tests.

The artificial weathering consisted of exposure of the test specimens for a period of 1000 hr. to a high intensity carbon arc approximating the frequency range of natural sunlight in combination with exposure to elevated temperature and water spray. The test was carried

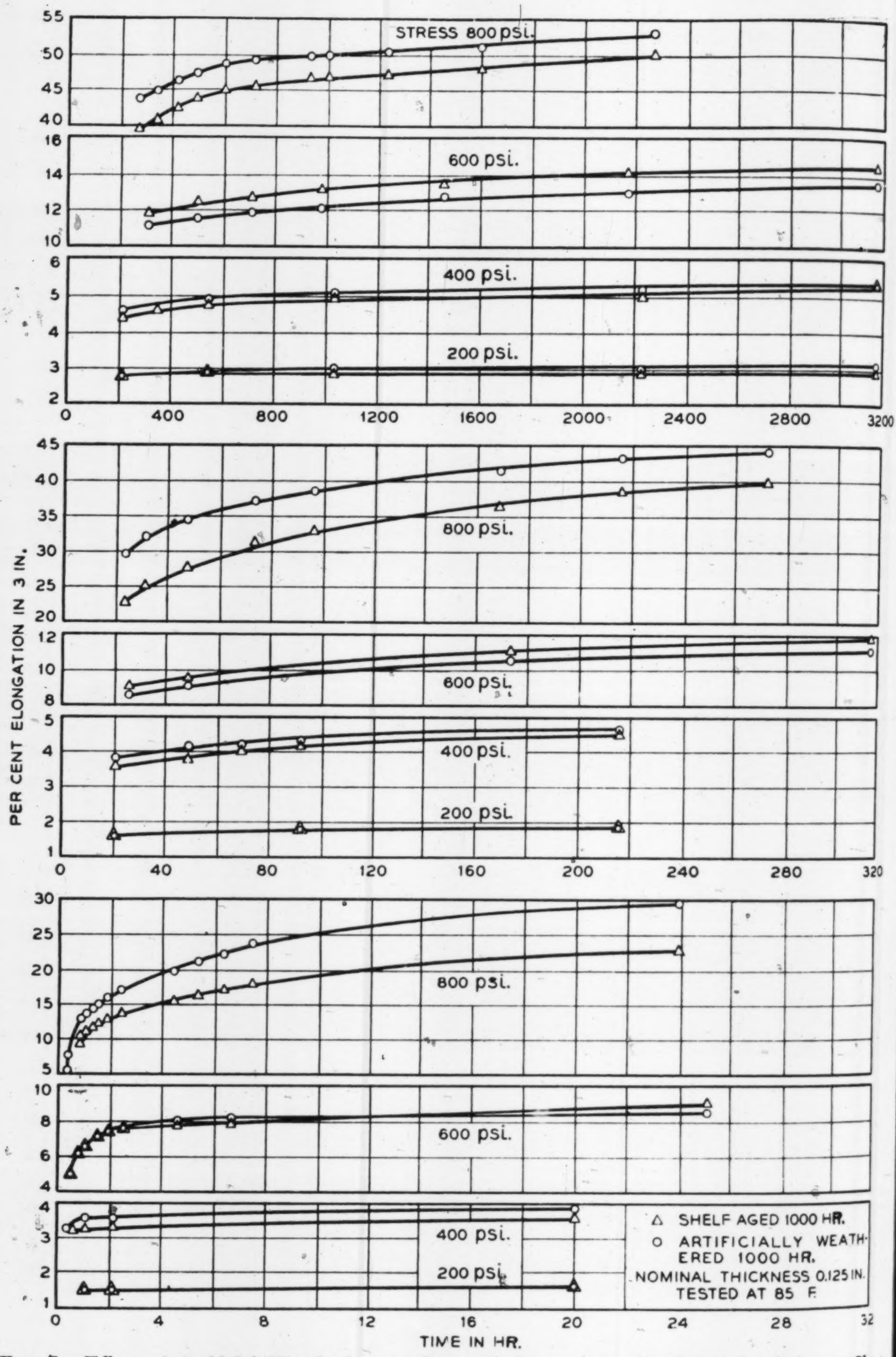

FIG. 7.—Effect of Artificial Weathering on Creep of Compression Molded Polyethylene. Sheet Containing 2 per cent Carbon Black and 0.2 per cent Antioxidant. (Lot D).

out in a modified National Model X-1A —Accelerated Weathering Unit from which the Corex D glass filters were removed. The exposure consisted of a series of 120-min. cycles, each of which included 30 min. in shadow followed by 90 min. of direct exposure to the light. Each cycle included a water spray at the beginning of the light exposure period. During exposure the surface of the specimen reached a temperature of approximately 194 F. (90 C.).

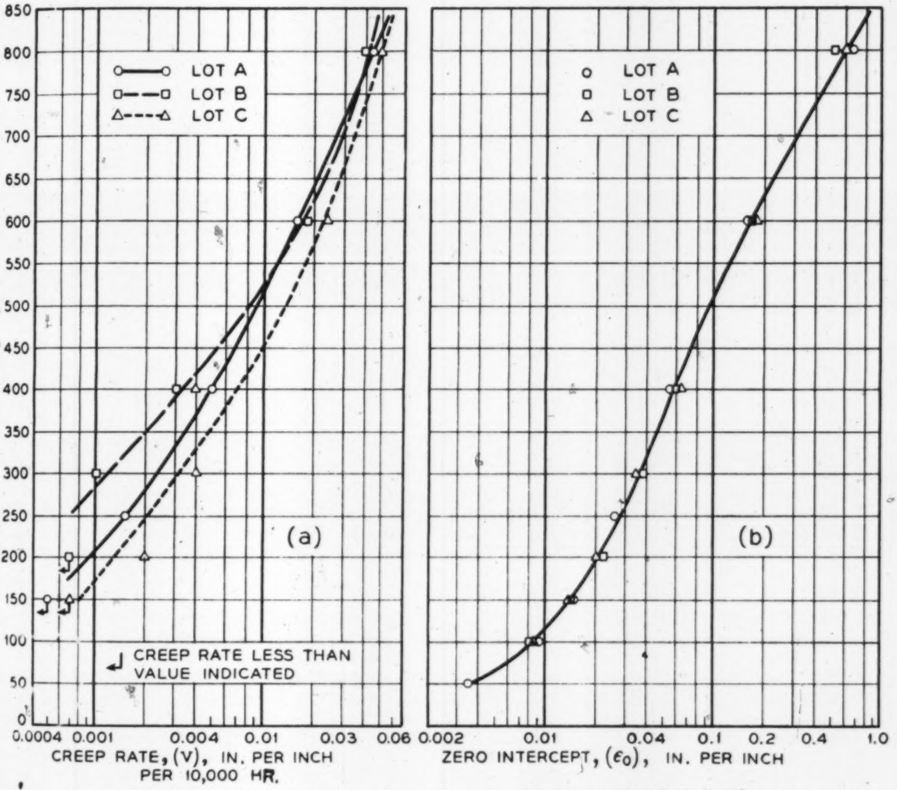

FIG. 8.—Creep Characteristics of Compression Molded Polyethylene Sheet.
(*a*) Stress *versus* Creep Rate (v).
(*b*) Stress *versus* Zero Intercept (ϵ_0).
Nominal Thickness 0.125 in. Tested at 85 F.

DISCUSSION OF RESULTS

General Creep Characteristics:

The creep characteristics of lots A, B, C, and D, polyethylene sheet, shown in Figs. 3, 4, and 5, respectively, are much the same. There is an initial rapid extension which increases in value with increasing stress. The initial rapid extension is completed within a few hours at low stresses but may require as long as 2000 hr. at higher stresses. This initial elongation is followed by a second stage of slow extension during which the creep rate decreases gradually and approaches but never quite attains a constant rate. This behavior—the high initial rate of extension followed by a period of less rapid creep—has also been reported for molded phenolic plastics (**4, 5, 6, 7**) cellulose acetate (**8**) and other thermoplastic materials (**7**).

Creep rates for lots A, B, and C after 10,000 hr. of test are shown in Fig. 8(*a*) for various stress levels. An associated curve, Fig. 8 (*b*), gives the corresponding strain intercepts at zero time for the creep rates shown in Fig. 8 (*a*). The strain intercept is an index of the amount of initial extension and becomes quite large, approaching 100 per cent elongation at high stresses. In this respect the polyethylene compounds, as do many other plastics, differ from metals which usually show relatively small creep in the initial stages.

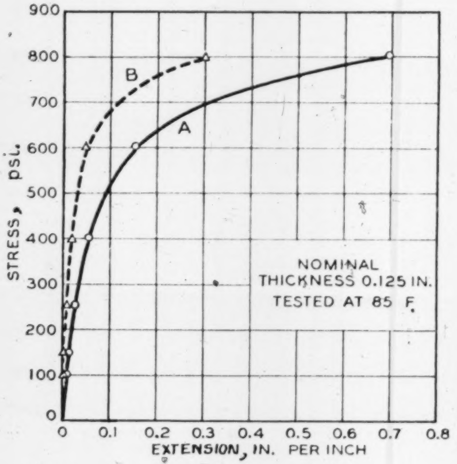

FIG. 9.—Creep Characteristics of Clear Compression Molded Polyethylene Sheet (Lot A)—Relation Between Stress, Permanent and Total Strain.

Curve A—Total Strain After 10,750 hr. of Creep.

Curve B—Permanent Deformation after 10,750 hr. of Creep Followed by 600 hr. Without Loading

Creep rate data for lots A, B, and C are not explicitly shown for time intervals of less than 10,000 hr., but such values can be derived from the elongation-time curves. If this is done, it is found that the creep rates are higher for time intervals of less than 10,000 hr., the rate decreasing with increasing time under load. For this reason creep rate data are not included in Fig. 8 (*a*) for lot D material which was under test for only 3500 hr. The lack of constancy of creep rate in the second stage, which differs from the behavior of most metals, suggests that creep studies on polyethylene and similar plastic compounds should be continued for a minimum period of 10,000 hr. if significant creep rates are to be obtained. Even after this period of time, the tangent creep rate may not be constant but will probably be only slightly less than the secant creep rate for the last 2000 to 5000 hr.

Whereas in metals the strain rate in the second stage of creep portrays reasonably well the engineering properties under sustained load, such is not the case with polyethylene compounds. There are two reasons for this: first the major part of the elongation of the polyethylene sample may occur in the initial stages and, secondly, the plastic will not sustain a reasonable amount of stress until it has undergone some strain. It is therefore important that the strain intercept data be presented with any creep rate data or that the total strain for any given stress be included in any comparison of the creep characteristics of polyethylene compounds. The latter method of presentation is used in Fig. 9 which shows the total strain after 10,750 hr. of stress for lot A material. This curve also shows that a high percentage of the initial strain is recoverable upon unloading, another marked difference in the creep behavior of polyethylene as compared to metals.

The general level of creep strength for the polyethylene compounds in comparison with some lead alloys is of interest in connection with cable sheathing applications. At stresses of engineering interest (below 400 psi.), the creep strength of the polyethylene, as indicated by the rate of creep during the second stage, is comparable to that of lead and its alloys. It is important to keep in mind, however, that this creep rate is only realized after a substantial initial elongation. For example, at a steady stress as low as 50 psi., the low "steady" creep rate operates only after the specimen has extended about 0.3 per cent in the initial stage of creep, whereas in lead sheathing alloys the extension at this low stress level is less than the precision of the measuring equipment. This phenomenon bears on the engineering use of polyethylene for cable sheath applications because if the polyethylene is to sustain the steady stress, the cable structure must be such as to permit freedom for the development of an initial strain of a substantial amount.

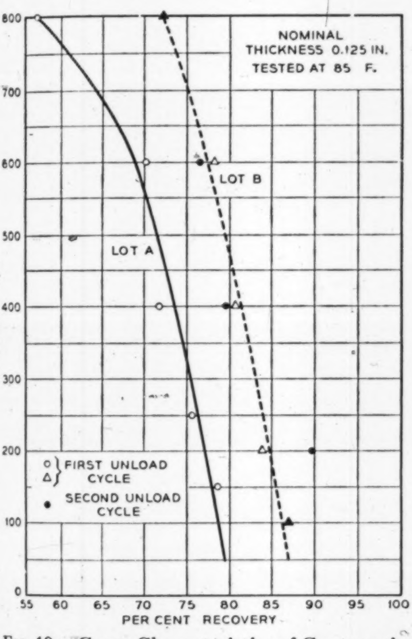

FIG. 10.—Creep Characteristics of Compression Molded Polyethylene Sheet. Per cent Recovery During Unloading Cycle.

Unload-Reload Strain Cycles:

During the course of the creep tests, studies were made to determine the strain recovery at various stress levels following an unloading cycle and the effect of such unloading upon the creep rate following reapplication of the load. The effect of one such unload-reload cycle on the creep of specimens of lot A material and two such cycles on the creep of specimens of lot B material are shown in Figs. 3 and 4. Substantial detail of the changes noted in the first unload-reload cycle are shown in Fig. 4. These data represent the strain changes which occurred at 85 F., the testing temperature, and would undoubtedly be somewhat different at other temperatures. As shown in Figs. 9 and 10, the strain recovery is an appreciable percentage of the total strain at all stress levels. Relaxation or elastic recovery upon removal of the steady load has also been reported in creep tests on molded phenolic plastics (**5**, **6**). A similar, but less marked, recovery for some of the other thermoplastic materials is likewise shown in short-time tests of only 100 hr. duration reported by Delmonte and Dewar (**7**).

A study of the data shown in Figs. 3 and 4 indicates that the "steady" creep rate is not materially affected by the unload-reload cycles. The prior history of one such cycle does not appear to have influenced the creep behavior during the second unload-reload cycle (Fig. 4) nor to have affected the subsequent creep behavior. It almost appears as if the test had been started initially from the condition of last unload. The elastic strain recovery in polyethylene is very much larger than that observed with metals where the recovery is generally insignificant in comparison with the inelastic plastic flow observed in the creep test. This difference in behavior requires a modification in the presentation of the data from that normally used for metals as was discussed in a preceding paragraph.

Comparison of Lots A, B, and C:

The data shown in Fig. 8 (*a*) on creep rates for lots A, B, and C polyethylene sheet after 10,000 hr. of continuous loading, and in Fig. 8 (*b*) for the corresponding zero strain intercepts admit of only limited general conclusions. However, it should be noted that there was no substantial difference in either the creep rates or the zero strain intercepts as a result of adding carbon black and antioxidant to the polyethylene. The similar creep characteristics of lots A, B, and C polyethylene sheet are even more clearly shown in Fig. 11 in which the total creep for each of the three lots is shown at various stress levels. The additions, however, were not made to the same lot of base compound or in the same amounts, which narrows somewhat the generality of any conclusions drawn from the data.

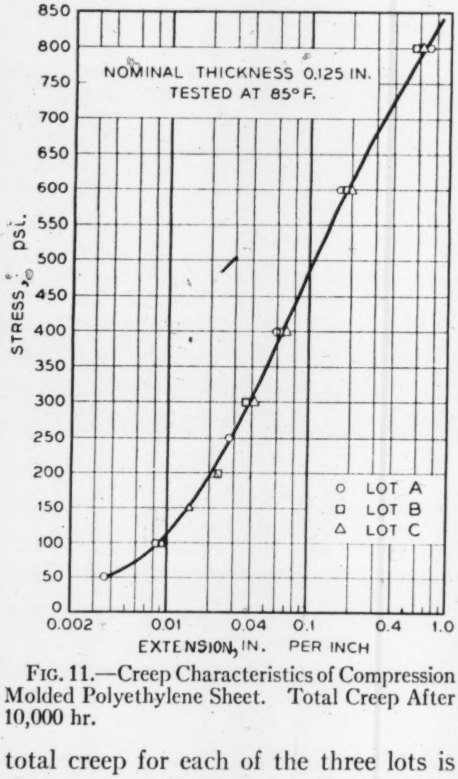

FIG. 11.—Creep Characteristics of Compression Molded Polyethylene Sheet. Total Creep After 10,000 hr.

Effect of Shelf Aging on Creep of Polyethylene:

It was observed during the course of these studies that shelf-aged samples had different creep characteristics than did specimens of the same lot tested soon after molding. This is illustrated in Fig. 6 (*a*) which shows that shelf-aged specimens had a much slower rate of creep at a stress of 1000 psi. than did unaged specimens. Furthermore, it should be noted that the unaged specimens failed at a stress of 1000 psi. in 28 hr. whereas the shelf-aged specimens are still unbroken after 3200 hr. This would indicate that aging has some effect upon the time-to-fracture, or the stress-rupture characteristics as it is generally termed.

It has likewise been observed in specimens first stressed at 800 psi. and then subjected to an increase in stress to 1000 psi. that fracture was delayed for at least several thousand hours. At 800 psi. the tests have extended over but a short period of time and hence show only the effect of shelf aging in the initial stage of the test. At this stress level (see Fig. 6 (*b*)), the shelf-aged specimens had a smaller immediate extension than did the unaged specimens and a longer period of time is required for the creep rate to approach a constant value. The general trend of the two curves shown in Fig. 6 (*b*), however, suggests that after several thousand hours the effect of aging prior to test at 800 psi. may become trivial. These data were obtained from exploratory tests and do not represent results from a sufficient number of samples to warrant any general conclusions but are given as interesting observations. However, other investigators, particularly Findley (8), have also observed that aging prior to test markedly reduces the total extension occurring during the first stage of creep in tests made on cellulose acetate sheet.

Effect of Artificial Weathering:

The effect of artificial weathering of specimens from lot D material prior to creep testing at stresses ranging from 200 to 800 psi. is shown in Fig. 7. The curves through the hollow circles represent tests on specimens which were artificially weathered for a period of 1000 hr. while the companion curves through the triangles represent tests on samples which were shelf aged for the same period of time prior to test. These tests, which cover 3500 hr. of sustained loading, show substantial agreement at stresses of 200 and 400 psi. At higher stresses the differences are not deemed significant. The data would indicate that artificial weathering does not materially change the creep characteristics of polyethylene containing carbon black and an anti-oxidant.

CONCLUSIONS

Creep tests on polyethylene indicate that the creep characteristics are essentially the same whether tested as clear compression molded sheet or as compression molded sheet containing additions of carbon black and an antioxidant. Unlike the metals, polyethylene shows high elastic and plastic deformation during the first stage of creep. The elastic component represents a high proportion of the total creep occurring during this period. Upon unloading, as much as 78 per cent of the total elongation is recoverable whereas in the case of metals little or no recovery is evident upon unloading. The creep tests on polyethylene at various stress levels indicate that even after 20,000 hr. of continuously applied load a steady creep rate has not been obtained, although the tangent creep rates indicate that there is only a small change in rate after approximately 10,000 hr. of continuous loading. Lead sheathing alloys, on the other hand, usually show a steady creep stage after only a few thousand hours under sustained load.

Shelf aging, after molding and prior to starting the creep test, appears to have some effect in increasing the creep strength in the initial period of the test. There is some indication that shelf aging, as well as prior understressing, delays stress-rupture at high stresses.

Artificial weathering for 1000 hr. did not significantly affect the creep characteristics of the polyethylene compound.

Acknowledgments:

The authors wish to acknowledge the valuable comments of Mr. V. T. Wallder in the discussion and preparation of the manuscript. The sheets molded at the Bell Telephone Laboratories were prepared by Mr. G. F. Brown, Jr.

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(2) C. G. Sinclair, Jr., "Exchange Cable: The Drama of Post-war Production," *Bell Telephone Magazine*, Vol. 27, p. 77 (1948).

(3) G. R. Gohn, S. M. Arnold, and G. M. Bouton, "Creep Tests on Some Extruded Lead and Lead-Alloy Sleeves and Tapes," *Proceedings*, Am. Soc. Testing Mats., Vol. 46, p. 990 (1946).

(4) H. Perkuhn, "The Creep of Laminated Synthetic Resin Plastics," *Luftfahrtforschung*, Vol. 18, No. 1 (1941); National Advisory Committee for Aeronautics, *Technical Memorandum No. 995*.

(5) David Telfair, T. S. Carswell, and H. K. Nason, "Creep Properties of Molded Phenolic Plastics," *Modern Plastics*, Vol. 21, p. 137, February, 1944.

(6) W. J. Gailus and David Telfair, "Creep Properties of Molded Phenolic Plastics at Elevated Temperatures," *Transactions*, Am. Soc. Mechanical Eng., Vol. 67, p. 253 (1945).

(7) J. Delmonte and W. Dewar, "Factors Influencing Creep and Cold Flow of Plastics," ASTM BULLETIN, No. 112, October, 1941, p. 35; reprinted in *Modern Plastics*, Vol. 19, Se[illegible] 1, p. 73 (1941).

(8) W. N. Findley, "Mechanical Tests of Cellulose Acetate—Part II on Creep," *Proceedings*, Am. Soc. Testing Mats., Vol. 42, p. 914 (1942).

DISCUSSION

MR. W. N. FINDLEY[1] (*by letter*).—The authors have presented some very interesting data on creep of a thermoplastic. These data provide a means of testing the applicability to this material of an observation the writer recently reported for creep tests of certain laminated plastics.[2] It was observed that the per cent increase in strain from one time (say the time immediately after loading) to another time was nearly constant for any value of stress at the given temperature for each laminate tested. This per cent increase has been called creepocity. It has been suggested that creepocity may prove to be a useful term to supplement creep rate in comparing the creep resistance of those materials to which creepocity is found to apply.

The writer measured the creep at three different times from the uninterrupted creep tests shown in Figs. 3, 4, and 5, of the paper. The times chosen were 0, 1000, 20,000 hr. for lot A material; 0, 400, 11,200 hr. for lot B; and 0, 500, 11,000 hr. for lot C. In making these measurements the writer has assumed that the instantaneous strain which occurred on loading was represented by the first test point shown for these tests and has used this as the initial strain.

From these data the per cent increase in strain (creepocity) was computed for the three time intervals shown in the accompanying Table I. These values show no consistent variation with stress, as was also observed for plastic laminates, and have about the same order of magnitude within each time interval and each material.

TABLE I.—TRUE STRESS, TRUE STRAIN, AND CREEPOCITY FROM CREEP TESTS OF POLYTHYLENE.

Material	Nominal Stress, psi.	True Stress, psi.		True Strain, in. per inch		Creepocity, per cent increase in strain[a]		
		Initial Time	20 000 hr.	Initial Time	20 000 hr.	Initial Time to 1000 hr.	Initial Time to 20 000 hr.	1000 hr. to 20 000 hr.
Lot A	50					100	100	0
	100					100	100	0
	150					131	131	0
	250					92	132	21
	400	410	426		0.063	100	150	25
	600	626	714	0.042	0.175	214	345	41.5
	800	1088	1400	0.308	0.560	78	108	17
		Initial Time	11 200 hr.	Initial Time	11 200 hr.	Initial Time to 400 hr.	Initial Time to 11 200 hr.	400 hr. to 11 200 hr.
Lot B	50					0	0	0
	100					133	167	14.3
	150					44.5	66.8	15.4
	200					46.1	84.7	26.3
	300	306	311		0.036	60	85	15.6
	400	413	425	0.032	0.059	63	87.8	15
	600	652	712	0.083	0.171	63	117.5	33.6
	800	1092	1248	0.309	0.445	31	54.7	18
		Initial Time	11 000 hr.	Initial Time	11 000 hr.	Initial Time to 500 hr.	Initial Time to 11 000 hr.	500 hr. to 11 000 hr.
Lot C	50					100	100	0
	100					60	80	12.5
	150					33.5	44.5	8.3
	200					33.3	53.3	15
	300	306	314			66.8	110	25.7
	400	413	426		0.064	84	113	15.9
	600	642	719	0.067	0.182	109	188	38
	800	976	1344	0.119	0.519	141	210	28.3

[a] The creepocities shown are based on the values of ordinary strain measured from Figs. 3, 4, and 5 of the paper.

There is, however, deviation from a constant value especially at both low and high stresses. At low stresses the deviations may be caused by the fact that the strains were not accurately known to the writer because of difficulties in accurately measuring the curves and possibly also because the precision of the strain readings reported by the authors allowed ±35 per cent possible variation for the smallest strains.

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[1] Research Associate Professor of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

[2] W. N. Findley and W. J. Worley, "Mechanical Properties of Five Laminated Plastics," *Technical Note 1560*, National Advisory Committee for Aeronautics, August, 1948.

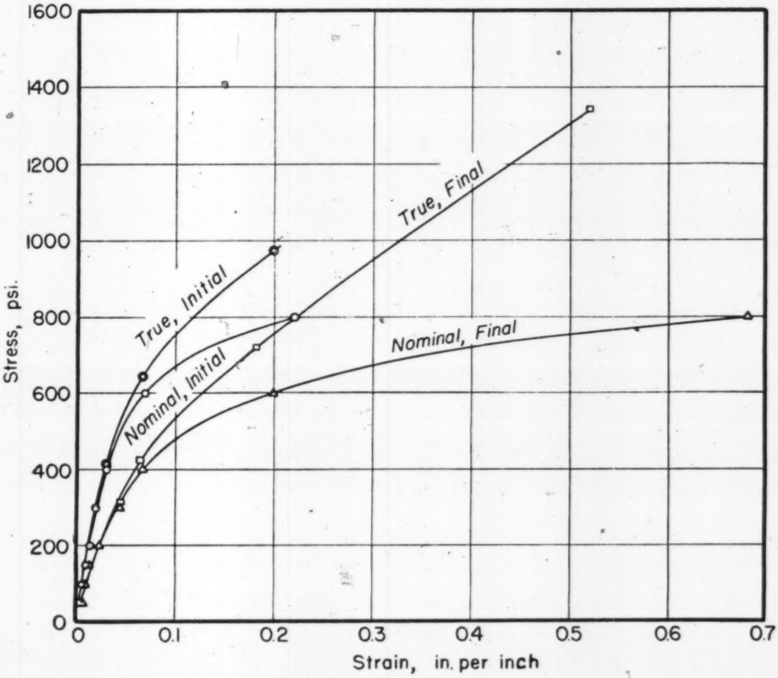

FIG. 12—Stress-Strain Curves Constructed from Creep Data for Lot C Polyethylene.

Showing Nominal Stress and Ordinary Strain Values; and True Stress and True Strain Values at the Start of the Creep Tests and at the End of the Creep Tests.

At high stresses there are two factors which may account for the variations in creepocity noted: (1) the initial strains shown in the table may in some cases have been measured after the load had been applied for a time sufficient for creep to have occurred, (2) the stress in the specimens carrying the highest loads changed considerably during the tests.

For elongations as large as observed in these tests (75 per cent in one case) substantial reduction in area of the specimen must occur with a resulting increase in stress at constant load. Also for such large elongations the ordinary definitions of strain based on the original length has been found[3] to be inconsistent. It has not been the custom to consider these factors for ordinary creep testing; but, for the purpose of this discussion corrections may be made as follows.

If the volume of material remains constant during straining and the straining is uniform over the gage length it may be shown[3] that the so-called true stress S' is given by the relation

$$S' = S\,(1 + \epsilon)$$

where S is the nominal stress and ϵ is the per cent elongation. Non-uniform straining, necking down, was not reported by the authors. However, if it occurred, the true stress would be larger even than calculated by the above equation.

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[3] P. Ludwik, "Elemente der Technologischen Mechanik," Julius Springer, Berlin (1909).

The definition of strain (called true strain) which has been suggested for use with large elongations is

$$\epsilon' = \int_{l_0}^{l} \frac{dl}{l}$$

which may be shown[3] to reduce to

$$\epsilon' = ln_e\,(1 + \epsilon)$$

where ϵ is the per cent elongation.

The values of true stress and true strain have been computed for the uninterrupted tests shown in Figs. 3, 4, and 5 of the paper for the initial test points of specimens at the highest stresses. These values are shown in Table I for values which differ significantly from the nominal values.

A diagram of stress *versus* strain for lot C material is shown as an example in the accompanying Fig. 12. Both nominal values of stress and strain as well as true values are shown for the initial values and also for the values of stress and strain after 11,000 hr. of creep.

Figure 12 indicates that the test at a nominal stress of 800 psi. had a true stress of 976 psi. immediately after loading and 1344 psi. at the end of the test. Thus in this example the stress increased 38 per cent during the test. This increase in stress for the highest stressed specimens may have a large effect on the creepocity.

It may also be of interest to consider what effect a change from nominal to true stress would have on the derived curves presented in the paper. A change from the nominal to true stresses would alter Figs. 8, 9, 10, and 11 of the paper markedly by making the highest stresses much higher. If all the creep tests could have been conducted at constant stress and true strain had been used there might also have been some change in the creep rates shown in Fig. 8(*a*).

The shape of the curves in Fig. 8(*a*) resulting from a change to true stress *versus* creep rate suggests that the data may fit a hyperbolic sine equation as postulated by the activation energy theory. The creep data for many metals and some plastics have been shown to fit this equation.[4]

The change to true stress changes the reverse curvature of the diagrams shown in Figs. 8(*b*) and 11 to curvature all of one sign which seems more reasonable. This change also makes the curves in Fig. 10 nearly straight lines.

The authors have stated "Upon unloading, as much as 78 per cent of the total elongation is recoverable whereas in the case of metals little or no recovery is evident upon unloading." It might be helpful in evaluating this situation if the authors would indicate what proportion of the recovery referred to was instantaneous and what portion was delayed recovery. The writer's recovery tests, most of which are unpublished, indicate that for some plastics the instantaneous recovery is nearly equal the instantaneous strain on loading.

If this is true of the present tests most of the observed recovery would be instantaneous and nearly equal to the initial instantaneous strain as is also true of metals. The difference between the recovery behavior of plastics and metals would then be found in the difference between the ratios of total strain after creep to instantaneous strain for plastics compared to that for metals.

It would also be of interest to know

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[4] W. Kauzmann, "Flow of Solid Metals from the Standpoint of the Chemical-Rate Theory," *Transactions*, Am. Inst. Mining and Metallurgical Engrs., Vol. 143, p. 57 (1941).

W. N. Findley, C. H. Adams, and W. J. Worley, "The Effect of Temperature on the Creep of Two Laminated Plastics as Interpreted by the Hyperbolic-Sine Law and Activation Energy Theory, *Proceedings*, Am. Soc. Testing Mats., Vol. 48, p. 1217 (1948).

whether the instantaneous recovery of specimens which had experienced large elongations was greater than the instantaneous strain on loading. This might be expected if the stiffness of the material was unaffected by the straining since the change in true stress on unloading was much larger than the change in the true stress on loading for the specimens which had experienced large elongations.

MR. J. W. WESTWATER[5] (*by letter*).—The information contained in this paper is very welcome, for the amount of published creep data for plastics is still very small. In some respects, however, the facts are too condensed. For creep tests it is always desirable to know the degree of control of temperature. For plastics, the degree of humidity control is of interest, even if the plastic is claimed to be impervious to moisture. It would also be profitable to know a few of the physical properties of the creep specimens. What were the static tensile strengths, static elongation at break, etc? Static stress-strain curves would add to the value of the paper.

MR. R. H. CAREY[6] (*by letter*).—The authors have contributed much toward an understanding of the mechanical properties of a relatively new material. The unusual properties of polyethylene have resulted in much confusion about its proper use.

In conjunction with the authors' paper, the writer would like to call attention to a paper which is planned for presentation at the American Chemical Society Meeting in September.[7]

In this paper, tensile stress-strain and torsional torque-deflection data for various molecular weight polyethylene resins over a temperature range from −125 C. to +25 C. are given. It is believed that such data will supplement the creep information presented here.

The authors state that "the major part of the elongation of the polyethylene sample may occur in the initial stages and, secondly, the plastic will not sustain a reasonable amount of stress until it has undergone some strain." The reference given above contains a partial explanation of this phenomenon in presenting data on the apparent modulus of elasticity of polyethylene. Under moderate rates of straining, the apparent modulus of elasticity of polyethylene (at 25 C.) varies between 20,000 and 40,000 psi. depending upon molecular weight and filler.

MR. C. H. ADAMS[8] (*by letter*).—The authors have made a notable contribution to the knowledge of the engineering behavior of plastic materials. It is particularly gratifying that the subject matter has been presented in such a manner that the engineering importance of the data obtained is given the emphasis it deserves.

Despite careful perusal of this paper, no information could be found regarding the molecular weight of the various polyethylene materials studied. This information would have served to characterize the materials and aided in the interpretation of the results.

It is interesting to note that the authors observed a similarity between the effect of shelf aging and prior understressing in delaying stress rupture at high stresses. Has any work been done to arrive at an explanation for the mechanisms responsible for this phenomenon? Is there any indication that shelf aging and prior understressing give rise to the same change in molecular aggregation?

The authors note that other investigators, particularly Findley, have observed that aging prior to test markedly reduces the total extension occurring during the first stage of creep. They point out that Findley's observations were made on cellulose acetate. It seems that the aging of cellulose acetate should be considered in a different light from that of polyethylene. The changes in physical properties of cellulose acetate with aging are due to (1) degradation of the resin and (2) loss of plasticizer whereas polyethylene aging proceeds as a degradation of the resin only, since it is an unplasticized material.

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[5] Assistant Professor of Chemical Engineering, University of Illinois, Urbana, Ill.

[6] Bakelite Corp., Bound Brook, N. J.

[7] R. H. Carey, G. J. Dienes, and E. F. Schulz, "Mechanical Properties of Polyethylene," to be published.

[8] Research Dept., Plastics Div., Monsanto Chemical Co., Springfield, Mass.

In conclusion, let me again commend the authors for this excellent paper.

MESSRS. G. R. GOHN, J. D. CUMMINGS AND W. C. ELLIS (*authors' closure by letter*).—In preparing the present paper, the authors have attempted to present data on one of the useful engineering properties of polyethylene. All four lots of polyethylene investigated were basically materials having a plasticity number of approximately D52 at 130 C. as determined with the Williams plastometer.[9] The use of such plasticity numbers is, in our opinion, preferable to the use of molecular weights in describing ethylene polymers. The tensile strength of the various polyethylene compounds ranged from 1600 to 1900 psi., while the elongation including cold drawing varied from 400 to 600 per cent in 1 in. Stress-strain curves, however, were not taken for the specific molded sheets used in these studies. The various lots differed primarily in the source of polymerized material, the date of manufacture, variation in the amounts of added carbon black and antioxidant used in compounding the several lots and in the details of the molding practices employed in their manufacture. As can be seen from Figs. 8 and 11, these variations have had only a nominal effect upon the over-all creep characteristics of the several lots.

All the creep tests described by the authors were made in a laboratory in which the temperature was controlled within the limits of 80 to 85 F. The humidity of the laboratory was not controlled during these tests and the authors believe that the creep characteristics are not significantly affected by variations in humidity.

The additional data on the properties of polyethylene, which Mr. Carey and his associates plan to present in a paper before the American Chemical Society, should be of considerable interest and will, undoubtedly, contribute to a better understanding of the polymer. Our own data on the effect of shelf aging and prestressing, although not conclusive, were included in the present paper with this idea in mind, but we have not yet considered the questions of mechanism and molecular aggregation which have been raised by Mr. Adams.

The stresses and strains reported in the present paper were computed from the initial cross-sectional areas and gage lengths, in accordance with general engineering practice. True stress and strain values can be derived, by those who are interested, from the data presented in the paper as Mr. Findley has done in preparing his Fig. 1. In his use of the authors' data he has assumed that the instantaneous strain which occurred upon application of the load was represented by the first test point shown in Figs. 3, 4, and 5 of the paper. Actually the first point shown in these three figures correspond to extensions as measured after a time interval varying from 15 sec. to 1 or 2 min. following application of the load. Because of the condensed time axis used in presenting the data on these figures, the points appear to correspond to zero time. Their use as such will lead to considerable error in the application in any equations involving strain values at zero time because the strain values are increasing rapidly during this time interval. In the case of the data presented in Fig. 7, the initial readings for the expanded time scale are accurately portrayed at the time interval as measured from zero time, and it is suggested that these data might be used to better advantage in Mr. Findley's analysis. Furthermore, the authors do not believe that significant instantaneous strain readings can be obtained. For example, in order to avoid any shock or impact loading, it is necessary to apply the load gradually to the creep test specimen. For higher stresses this time period may be as much as 5 sec. Under such conditions instantaneous strains tend to merge into the points on the creep curve with only a very slight change in slope. The behavior undoubtedly takes place at lower loads but to a lesser degree. Similarly, we do not believe that a significant comparison can be made between instantaneous recovery upon unloading and instantaneous strain upon reloading. The authors would not wish to go beyond the evidence shown in Fig. 4 which shows that both the initial recovery upon removal of the load and the initial extension upon reloading are quite rapid.

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[9] Bureau of Ships Specification on Polyethylene Dielectric for Radio Frequency Cables; RE 9172.

Figures 8(*b*) and 11 are derived from elongation-time curves in which the true stress is constantly changing. The authors are, therefore, at a loss to know what significance can be attached to the true stress plots suggested by Mr. Findley. Mathematically, in the case of Figs. 8(*a*) and 10, true stress values could have been used equally well in place of nominal stress values in plotting the test results, but such calculations implicitly assume that the creep data on polyethylene are independent of the prior strain history. We do not believe that this assumption is valid. Some evidence in support of this belief is presented on page 1150 of the paper.

In conclusion, the authors have been encouraged by the discussion stimulated by the publication of their data on the creep characteristics of compression molded polyethylene and wish to take this opportunity to thank those that have contributed to the written discussion.

CREEP-TIME RELATIONS FOR POLYSTYRENE UNDER TENSION, BENDING, AND TORSION*

By Joseph Marin[1] and George Cuff[1]

Synopsis

In this paper, creep-time relations for polystyrene subjected to tension, bending, and torsion were obtained. The influence of the magnitude of the stress and time upon the creep deformations was determined for each of the foregoing types of stress. Control tests and stress-strain or load-deformation relations were obtained for simple tension, compression, simple bending, pure bending, and torsion.

A number of methods of interpretation of the creep test results were applied for the purpose of obtaining a suitable stress-creep-time empirical relation. It was found that a log-log relation between the 1000 hr. creep rate and stress approximately represents the data for the three types of stress considered. Theoretical values of the creep rates for bending and torsion, based on the tension log creep rate - log stress relation, agreed approximately with the actual creep rates obtained in the bending and torsion tests.

The available information on the mechanical properties of high polymers is rather limited. For this reason an investigation of the mechanical properties of polystyrene was conducted and is reported in this paper. The results given include the mechanical properties under simple static tension, compression, bending, and torsion stresses. The foregoing control tests were made in order to specify as completely as possible the material tested. In addition to the usual tension creep-time relations, creep-time relations in pure bending and torsion were obtained.

Stress-Strain Relations for Various Simple Stresses

Material Tested:

The material tested in this investigation was a grade of polystyrene manufactured by the Monsanto Chemical Co. and known commercially as Lustrex LX. Its average molecular weight as reported by the Monsanto Plastics Laboratory is between 67,600 and 68,700 (as determined in accordance with the Staudinger method). The material tested was molded in the form of flat sheets 12 by 12 in. with a thickness of $\frac{1}{2}$, $\frac{3}{4}$, or 1 in. All the material was examined under polarized light before use, and every effort was made to obtain essentially stress-free sheets. The average hardness of the sheets, using the Rockwell M scale, was found to be M 78.

A thermoplastic material was selected rather than a thermosetting plastic because of its greater homogeneity and because there is little information available on the creep properties of these materials under various stress conditions. Polystyrene was chosen because it could be produced essentially without directional properties and because any residual stresses present after molding could be easily detected.

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* Presented at the Fifty-second Annual Meeting of the Society, June 27–July 1, 1949.

[1] Professor of Engineering Mechanics and Research Assistant, respectively, Pennsylvania State College, State College, Pa.

Test Specimens:

Specimens for control tests in tension, compression, bending, and torsion of dimensions shown in Fig. 1 were machined from the flat sheets. At least five specimens were tested for each type of loading condition. Prior to testing, the specimens were kept for at least 72 hr. in a room with controlled humidity and temperature where the relative humidity was held at 50 ± 2 per cent and the temperature at 77 ± 2 F.

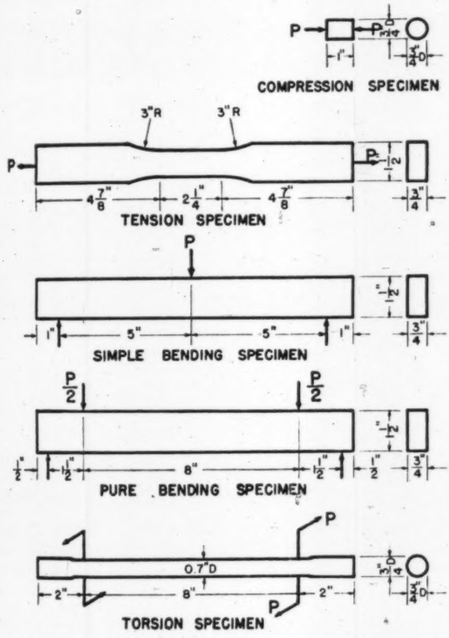


FIG. 1.—Control Test Specimens of Polystyrene.

Control Test Results:

All control tests except the torsion tests were made in a 60,000-lb. capacity Baldwin Southwark Tate-Emery universal hydraulic machine. The average values of the significant mechanical properties for the various types of stresses are summarized in Table I and the stress-strain or load-deformation curves are shown in Figs. 2 to 6. In these graphs, the circles with crosses represent fracture while the open circles represent test points. In all tests the rates of straining (rates of crosshead motion) were maintained approximately equal to values recommended by the A.S.T.M. Standards.

In making the *tension control tests*, a type A-1 SR-4 electrical strain gage was used for measuring the strains. Load-deformation readings were taken to rupture as shown in Fig. 2. Figure 2 shows that the plastic range is practically nonexistent, and hence the yield, ultimate and fracture strengths are essentially the same value.

TABLE I.—MECHANICAL PROPERTIES OF POLYSTYRENE (LUSTREX).

Type of Test	Modulus of Elasticity, psi.	Nominal Fracture Strength, psi.	Ductility at Fracture, per cent	Energy to Fracture, in-lb. per cu. in.
Tension	450 000	5 700	1.35	37.1
Compression	450 000	(12 400)[a]	....	(171)[a]
Torsion	170 000	5 400	3.1	41
Simple bending	470 000	7 350[b]	....	7[c]
Pure bending	520 000	7 800[b]	....	14[c]

[a] Yield Strength based on 0.005 offset and energy absorbed up to yield as determined from the formula $S_y^2/2E$.

[b] Based on use of formula $S = \frac{My}{I}$ and experimental value of $M_{\max}$.

[c] Based on input energy divided by volume of test piece.

In making the *compression control tests*, a π gage with ¼-in. gage length was used. By means of which compressive strains greater than 2 per cent were measured. The compression stress-strain curves shown in Fig. 3 indicate that there is some plastic flow. This plastic flow would be considerably more if the tests were not stopped soon after yield was reached. The stress and strain values used in plotting Fig. 3 were nominal val-

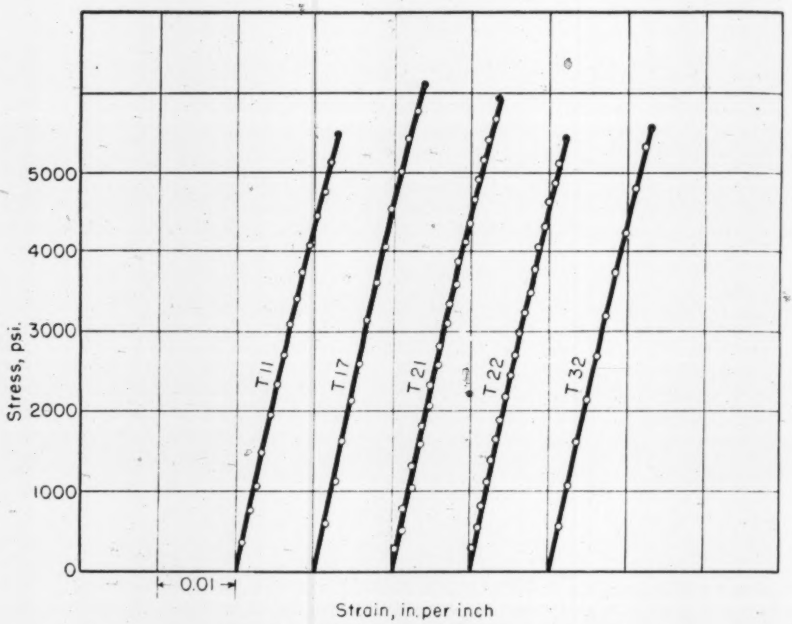


FIG. 2.—Tension Test of Polystyrene.

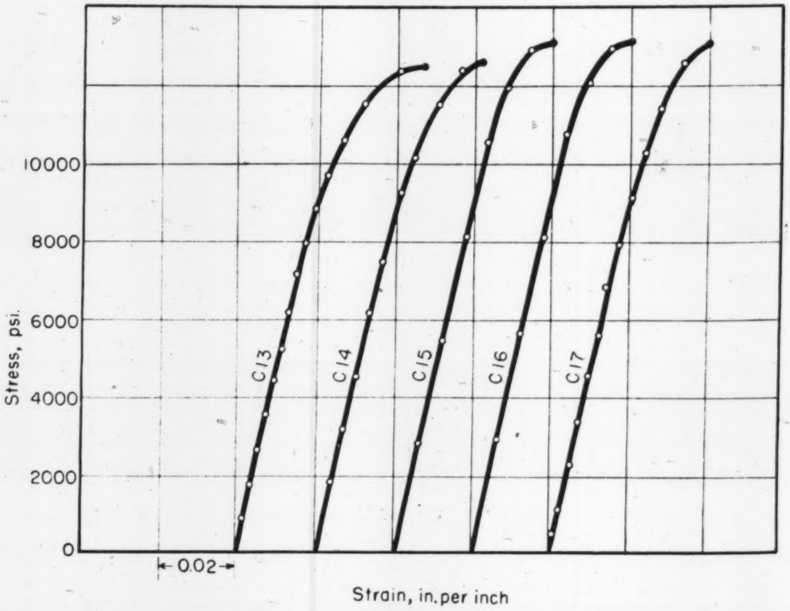


FIG. 3.—Compression Test of Polystyrene.

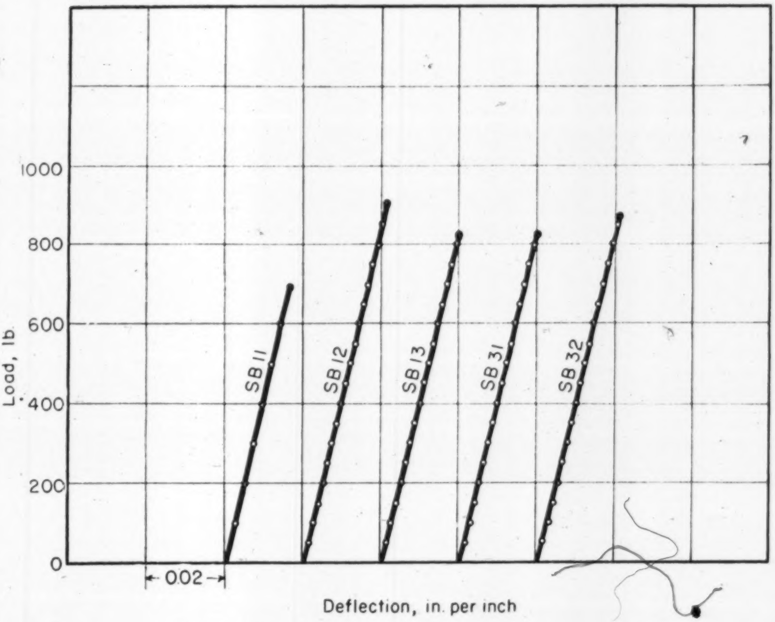


FIG. 4.—Simple Bending Test of Polystyrene.

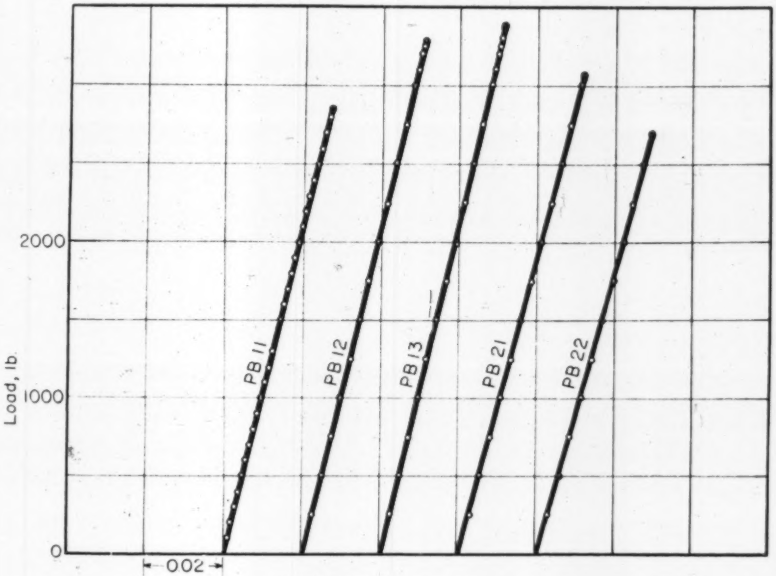


FIG. 5.—Pure Bending Test of Polystyrene.

ues and not true values. The resilience in compression for polystyrene is much greater than in tension since the energy absorption based on yield strength was found to be 171 in-lb. per cu. in. for compression and 37 in-lb. per cu. in. for tension.

In the compression tests, strain readings were recorded for both the lateral and longitudinal strains. From the ratio of these strains Poisson's ratio was found to be between 0.31 and 0.32.

The *bending control tests* were of two types, a simple bending and a pure bending test, as illustrated in Fig. 1. For both types of bending tests, the deflection was measured at the center by means of a dial gage reading to 0.0005 in. The load-deflection curves are shown in Figs. 4 and 5. Up to fracture the load-deflection relation is linear. The modulus of elasticity values, E, for simple bending calculated from the load-deflection equation, were found to be slightly higher than for simple tension. For pure bending this difference is greater due probably to the limitations of the beam formula and to the restraint against free rotation at the points of support.

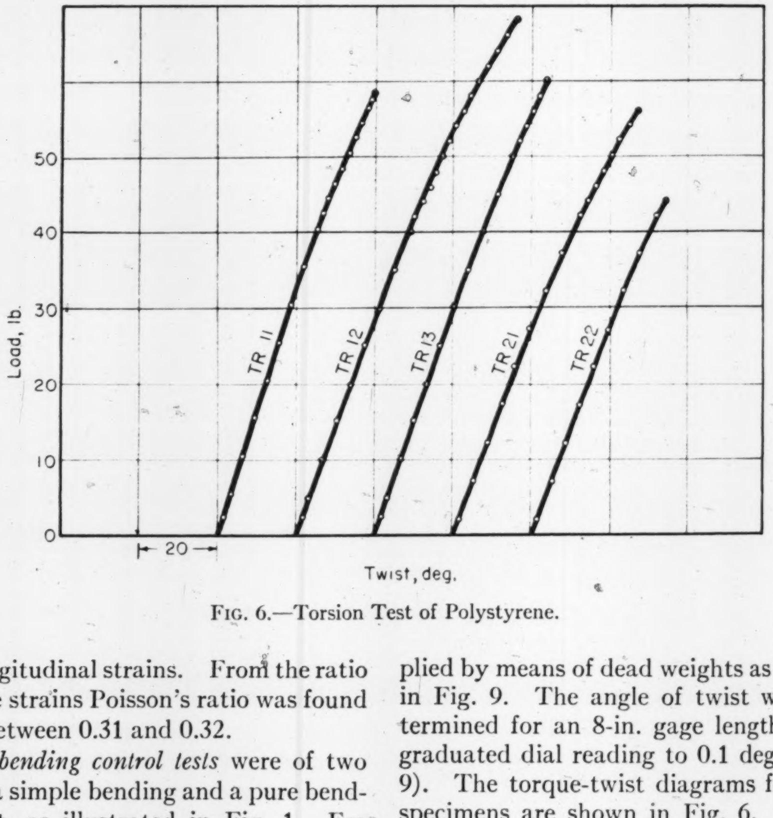
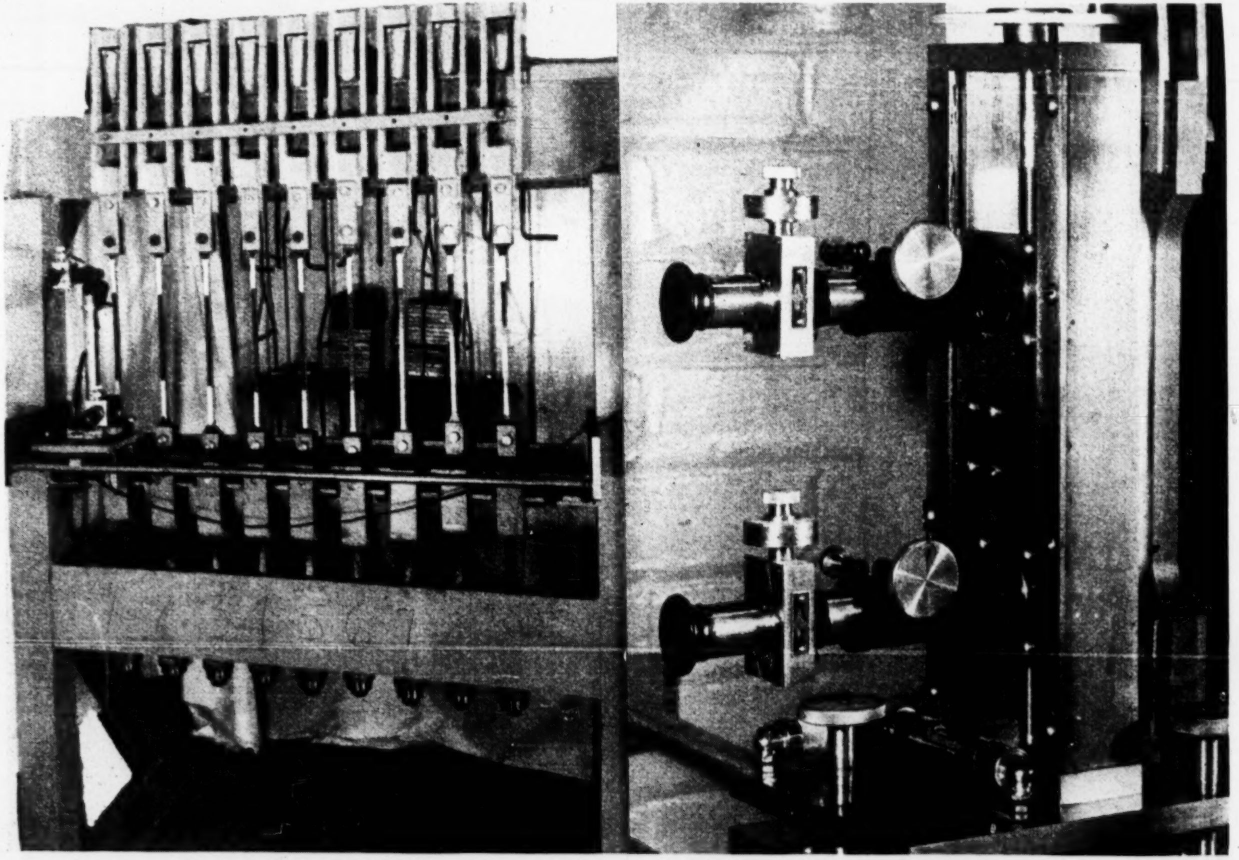


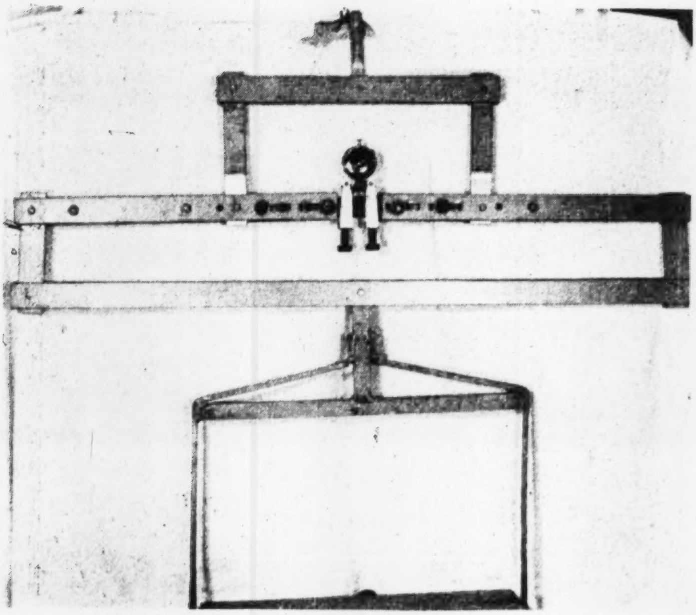
FIG. 6.—Torsion Test of Polystyrene.

The *torsion control tests* were made in a specially designed machine similar to that used for the measurement of torsion creep (Fig. 9). The torsion load was applied by means of dead weights as shown in Fig. 9. The angle of twist was determined for an 8-in. gage length by a graduated dial reading to 0.1 deg. (Fig. 9). The torque-twist diagrams for five specimens are shown in Fig. 6. Slight evidence of plastic distortion is indicated by the curves in Fig. 6. Using the average value of the modulus of elasticity in shear of 1.7×10^5 psi. and a value of Poisson's ratio of 0.315 as determined from the compression tests, the modulus of elasticity in tension as determined theoretically is $E = 4.47 \times 10^5$ psi. This value is in good agreement with the actual tension value of $E = 4.5 \times 10^5$ psi.



(*a*) Tension Creep Machine (*b*) Microscope Stand

FIG. 7.—Tension Creep Machine and Microscope Stand for Strain Measurement.



Single Bending Creep Unit

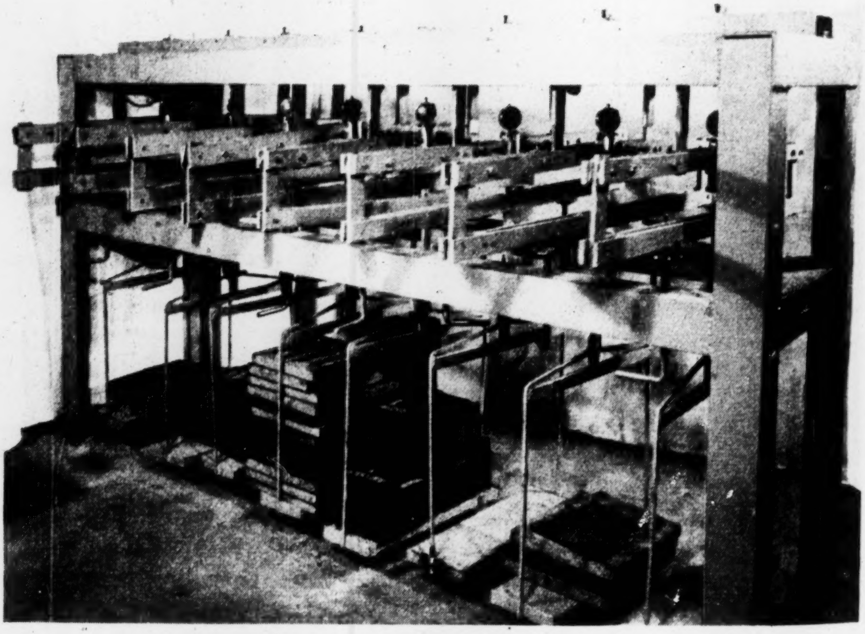
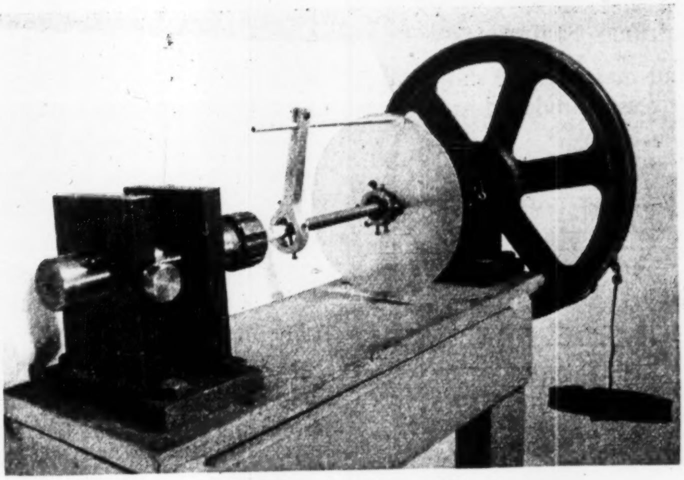


FIG. 8.—Bending Creep Machine.



Single Torsion Creep Unit

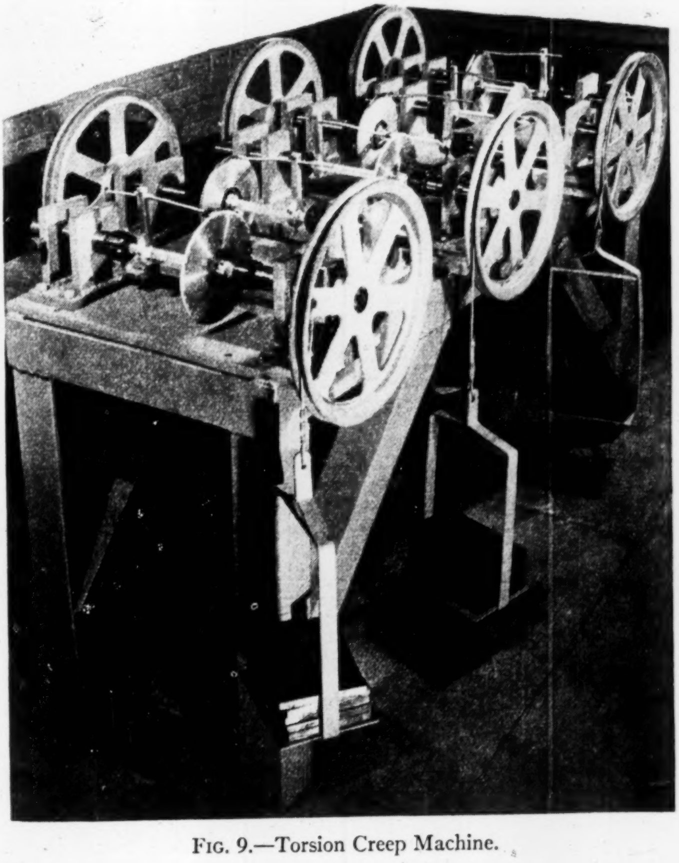


FIG. 9.—Torsion Creep Machine.

CREEP-TIME RELATIONS FOR VARIOUS SIMPLE STRESSES

When some materials are subjected to loads, the stresses produced are accompanied by deformations which increase in magnitude with time. These deformations called creep deformations, are in addition to the elastic deformations and occur for some materials at normal temperatures and low stresses. For purposes of design it is important to know what creep deformation or creep rate might be expected for a given stress in order to prevent undesirable deformations in a machine or structural part.

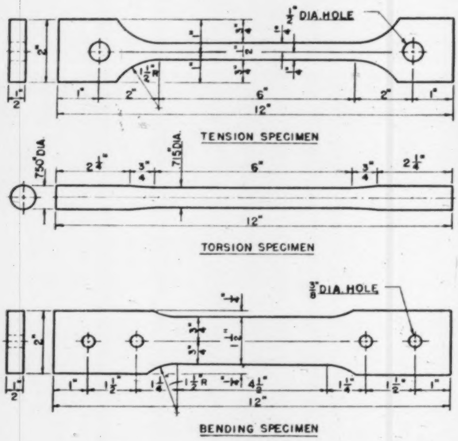


FIG. 10.—Dimensions of Specimens for Creep Tests.

It is important to realize that the presence of creep in a material influences the stress distribution in bending and torsion. That is, the stresses are no longer linearly distributed and the maximum stresses on the outer fiber are less than the theoretical stress calculated by the elastic theory (1).[2]

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1174.

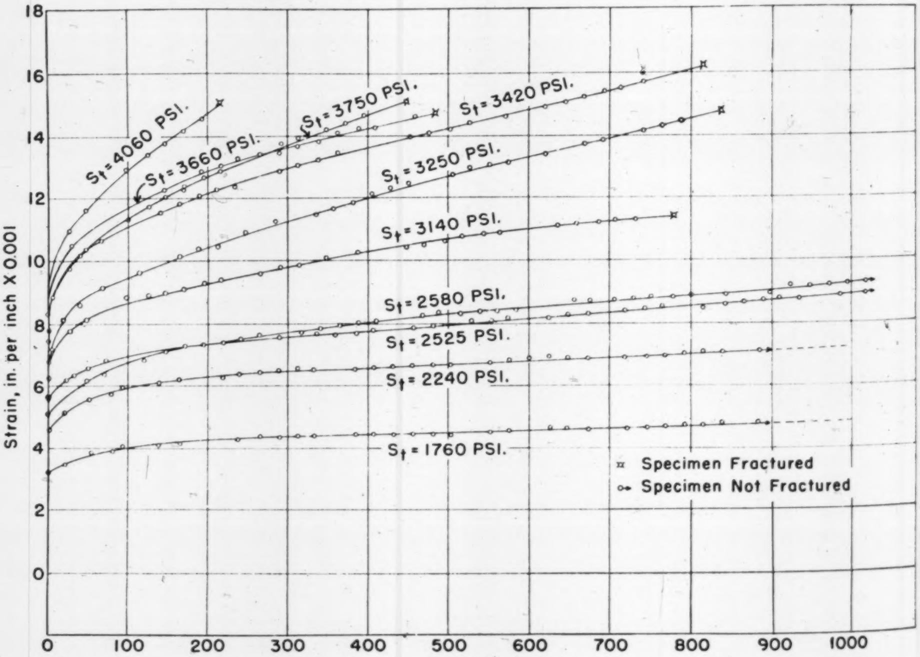

FIG. 11.—Tension Creep Time Relations.

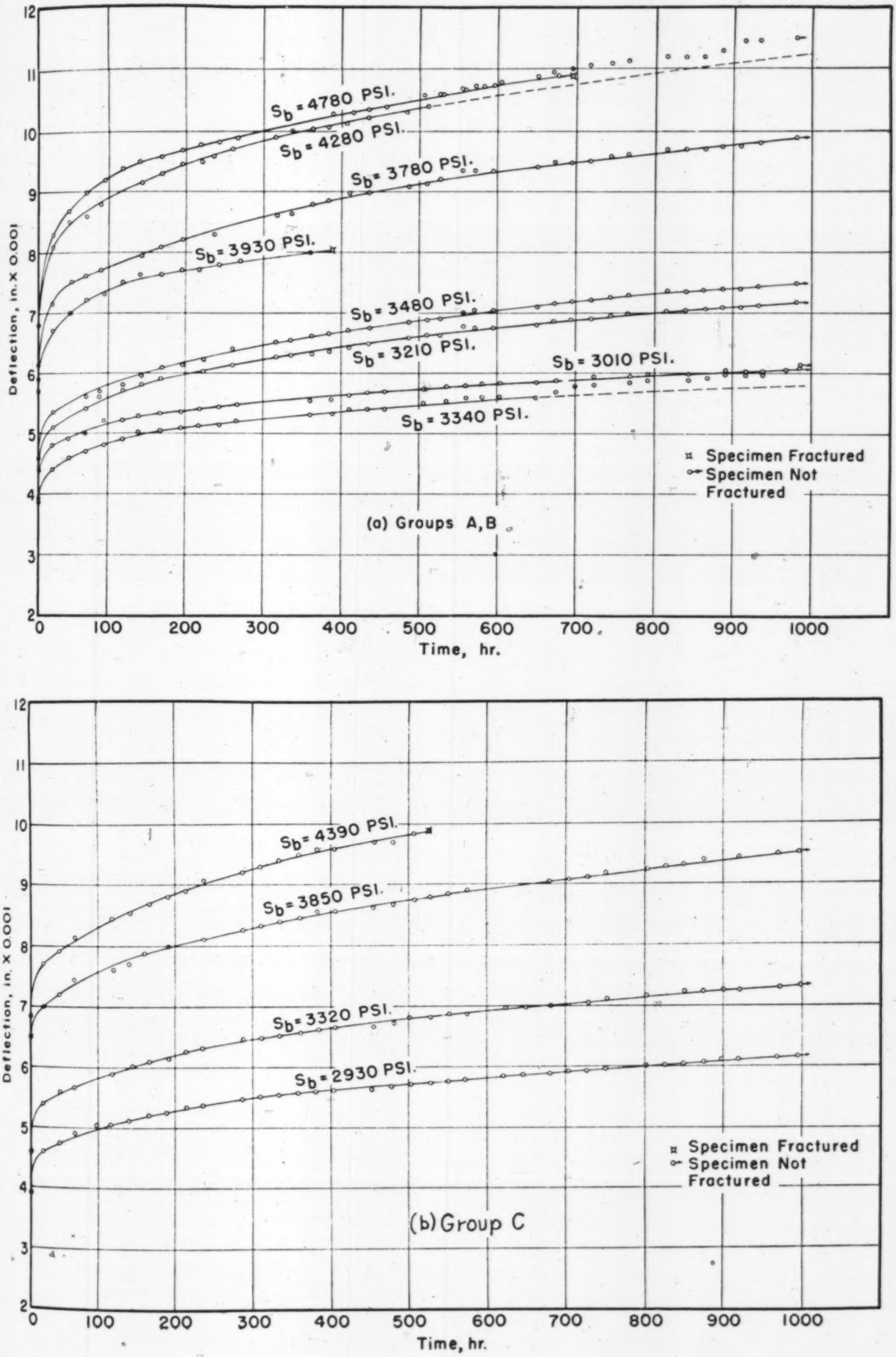

FIG. 12.—Bending Creep-Time Relations.

Most creep tests have been made in simple tension. Although the relative creep resistance of materials is indicated by the tension creep tests, there are many applications in which the applied loads do not produce simple tension. For this reason, the present investigation includes a study of the creep-stress relations not only for simple tension but also for pure bending and pure torsion.

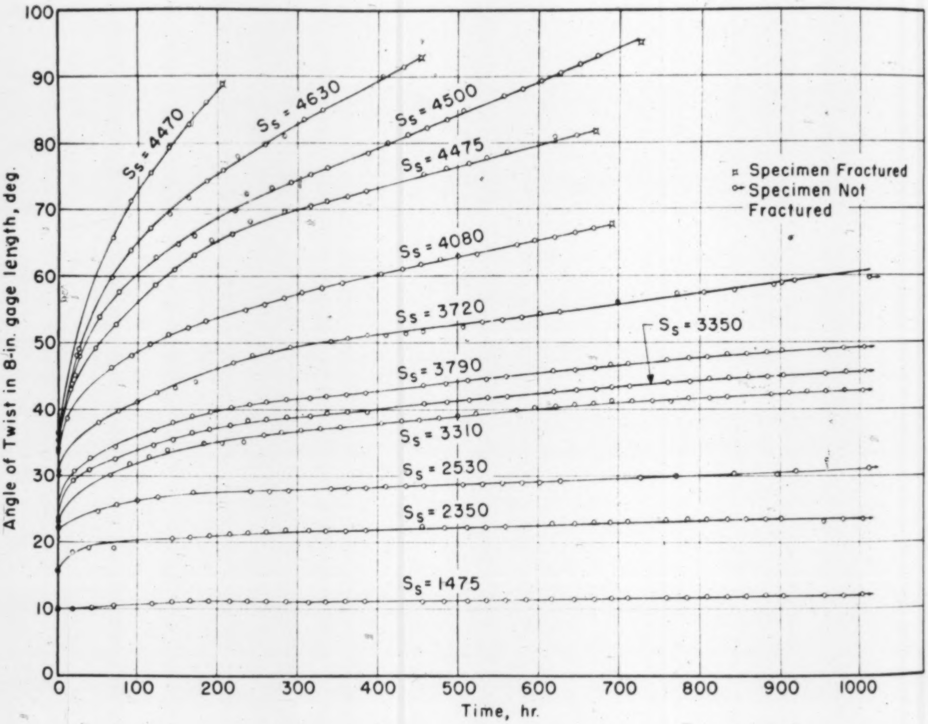

FIG. 13.—Torsion Creep-Time Relations.

Test Procedure:

All the creep tests were made in a creep laboratory in which the temperature was maintained at 77 ± 2 F., and the relative humidity was maintained at 50 ± 2 per cent. The humidity was kept essentially constant by means of both a humidifier and dehumidifier. Heating units with automatic controls were used to maintain a constant temperature. The testing machines used for the tension, torsion, and bending creep tests are shown in Figs. 7, 8, and 9. The details of the construction and operation of these creep testing machines are given in an earlier paper (2).

The dimensions of the specimens used for the tension, pure bending, and pure torsion tests are shown in Fig. 10. The creep strains in tension were measured to 0.00005 in. for a 5-in. gage length, using the micrometer microscope stand shown in Fig. 6. The creep deflection for the pure bending creep tests were measured for a 2-in. gage length by means of dial gages reading to 0.0001 in. The angles of twist for the creep torsion tests were measured over a 6-in. and 8-in. gage length by means of twistmeters equipped with verniers reading to 0.1 deg.

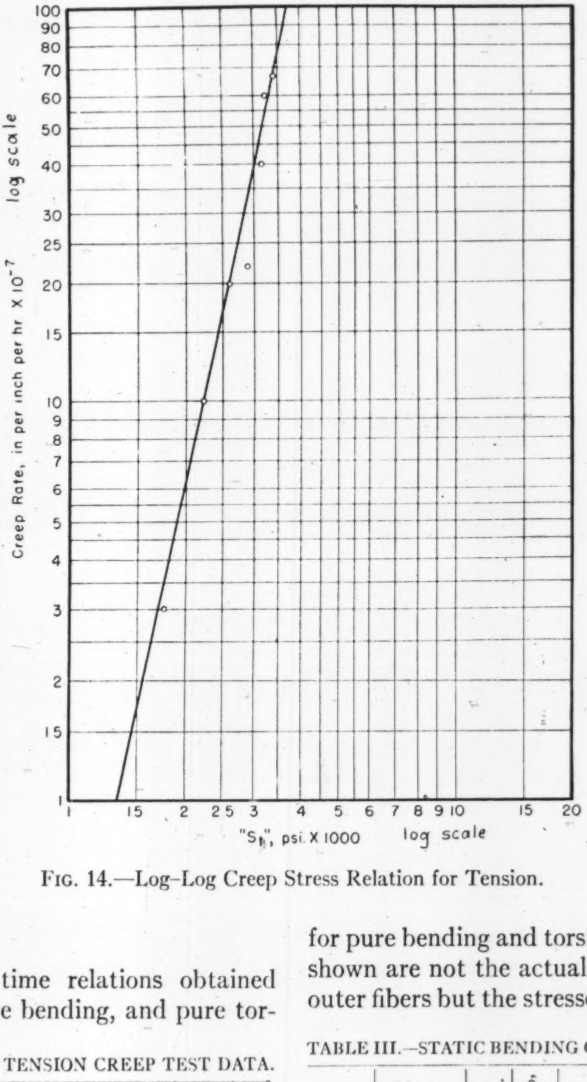

FIG. 14.—Log–Log Creep Stress Relation for Tension.

Test Results:

Deformation-time relations obtained for tension, pure bending, and pure torsion are shown in Figs. 11, 12, and 13 for various stress values. In Figs. 12 and 13 for pure bending and torsion, the stresses shown are not the actual stresses on the outer fibers but the stresses calculated by the elastic theory. Furthermore, the deformations plotted in Figs. 11, 12, and 13 include both the elastic and creep de-

TABLE II.—STATIC TENSION CREEP TEST DATA.

Specimen	Area, sq. in.	Load, lb.	Stress, S_t, psi.	Creep Rate, in. per in. per hr.	Creep at 1000 hr., in. per inch
No. 1.....	0.250	857	3420	66×10^{-7}	[a]
2.....	0.220	715	3250	60	[a]
3.....	0.264	830	3140	40	[a]
4.....	0.213	550	2580	22	9.3×10^{-3}
5.....	0.390	988	2525	20	8.9
6.....	0.362	808	2240	10	7.2
7.....	0.363	629	1760	3	4.9

[a] Specimens fractured before 1000 hr.

TABLE III.—STATIC BENDING CREEP TEST DATA

Specimen	Dimensions, in.		Moment, M_o in-lb.	Stress, S_b, psi.	Creep Deflection Rate, in. per hr.[a]	Creep Deflection at 1000 hr., in.[a]
	b	d				
No. 1...	0.491	1.502	696	3780	1.70×10^{-6}	9.91×10^{-3}
2...	0.488	1.502	641	3480	1.30	7.50
3...	0.490	1.504	614	3320	1.10	7.30
4...	0.525	1.500	593	3010	0.72	6.05
5...	0:490	1.500	590	3210	1.20	7.16
6...	0.504	1.501	553	2930	0.92	6.16

[a] Creep Rates and Creep Deflections are given for a 2-in. gage length.

formations in keeping with usual procedure.

Analysis of Test Results:

An examination of the creep-time diagrams in Figs. 11, 12, and 13 shows that after the initial stage of creep the creep rate remains approximately constant and can be taken as constant for practical purposes. The values of these constant creep rates, C, are shown in Tables II, III and IV for the three types of stress and for the various stress values. The stress values listed in Tables III and IV are based on the usual elastic stress formulas and do not represent the actual stresses on the outer fibers. Tables II, III, and IV also show the creep deformations at 1000 hr. Inspection of the creep and creep rate values given show that the creep and creep rate increase with increasing stress.

Various methods of interpretation were applied to the foregoing tension creep test results in an attempt to obtain an empirical relation defining the creep strain in terms of the stress and time (3, 4). Although these attempts were not successful, it was found that the minimum constant creep rate C in tension varied linearly with the stress when plotted on log-log paper (Fig. 14). That is, the creep-rate-stress relation was found to be defined by:

TABLE IV.—STATIC TORSION CREEP TEST DATA.

Specimen	Diameter, in.	Twisting Moment, M_t, in-lb.	Shear Stress, S_s, psi.	Creep Rate, deg. per in. per hr.	Creep Angle at 1000 hr., deg. per in.
No. 1	0.717	326.0	4500	6.12×10^{-3}	[a]
No. 2	0.717	305.5	4220	3.82	[a]
No. 3	0.706	280.0	4080	3.35	[a]
No. 4	0.720	272.0	3720	1.83	7.46
No. 5	0.719	269.5	3790	1.50	6.18
No. 6	0.716	241.0	3350	1.25	5.70
No. 7	0.698	221.0	3310	1.03	5.34
No. 8	0.710	178.0	2530	0.60	3.90
No. 9	0.727	177.0	2350	0.47	2.90
No. 10	0.731	113.1	1475	0.20	1.50

[a] Specimen broke in less than 1000 hr.

$$C = BS^n \qquad (1)$$

where B and n are experimental constants.

Values of $B = 6.658 \times 10^{-22}$ and $n = 4.53$ were obtained using Fig. 14.

Assuming the creep rate-stress relation given by Eq. 1, the theoretical creep rate for pure bending has been shown to be (5),

$$C_b = \left(\frac{y_m}{t}\right) = \frac{L^2}{8D} M^n \qquad (2)$$

where:

n = the experimental constant n in Eq. 1 for tension creep,

L = the gage length,

M = the bending moment,

$\frac{y_m}{t} = C_b$ = creep rate in bending.

and

$$D = \frac{(2b)^n \left(\frac{h}{2}\right)^{2n+1}}{B\left(2 + \frac{1}{n}\right)} \qquad (3)$$

where:

b = the width of the specimen,

h = the depth of the specimen, and

B = the experimental constant in Eq. 1 for tension creep.

The theoretical relation between the creep rate and moment as given by Eq. 2 is compared with the experimental values

TABLE V.—COMPARISON OF THEORETICAL AND EXPERIMENTAL BENDING CREEP RATES.

Specimen	Bending Moment, M_o, in-lb.	Creep Rate, in per hr.[a]		Difference, per cent
		Experimental	Theoretical	
No. 1	696	1.70×10^{-6}	1.65×10^{-6}	−3
No. 2	641	1.30	1.12	−14
No. 3	614	1.10	0.93	−15
No. 4	593	0.72	0.75	4
No. 5	590	1.20	0.75	−35
No. 6	553	0.92	0.57	−38

[a] Creep Rates are given for a 2 in. gage length.

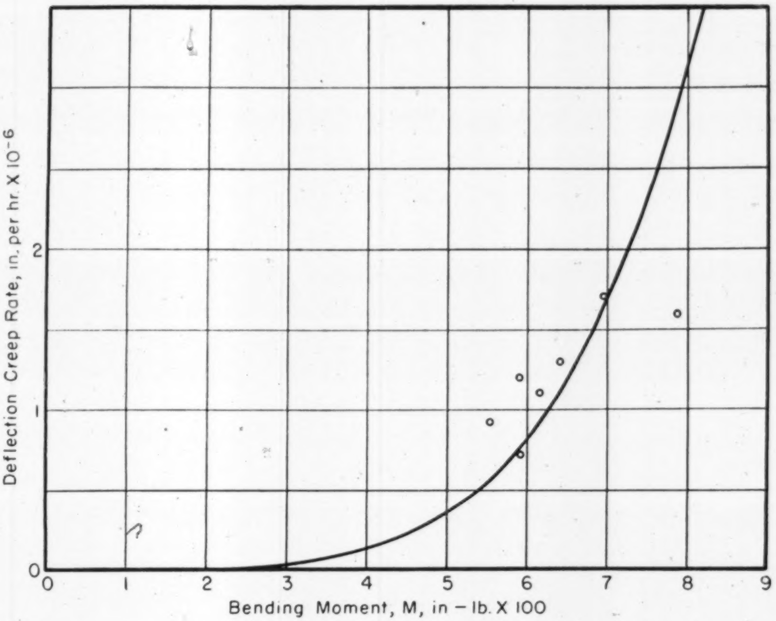

FIG. 15.—Comparison of Experimental and Theoretical Bending Creep Rates.

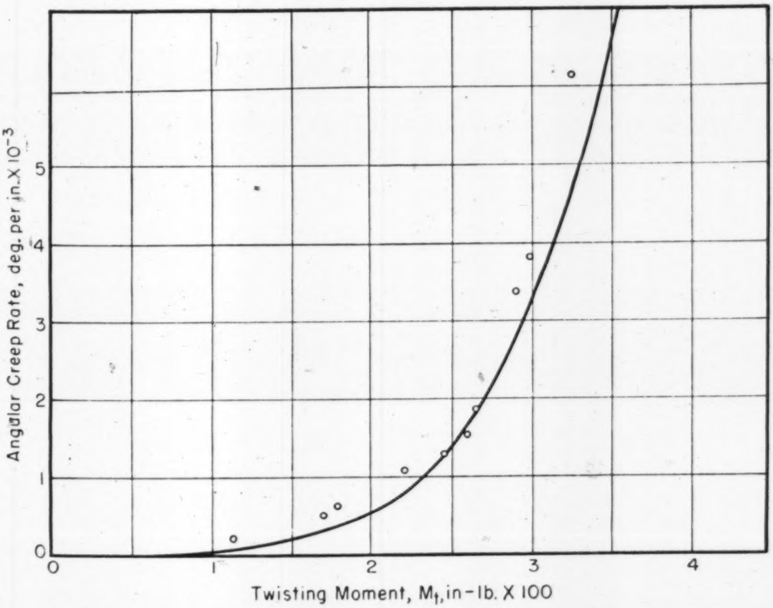

FIG. 16.—Comparison of Experimental and Theoretical Torsion Creep Rates.

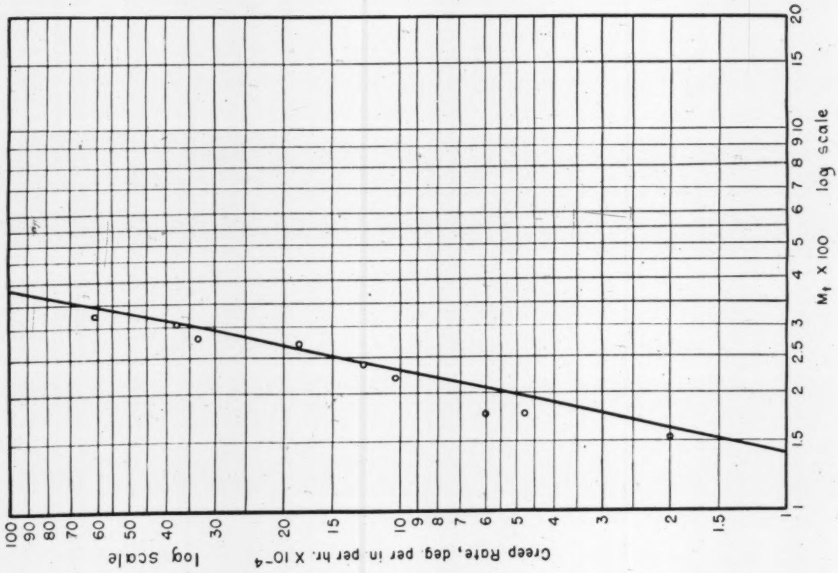

FIG. 18.—Log-Log Creep Stress Relation for Torsion.

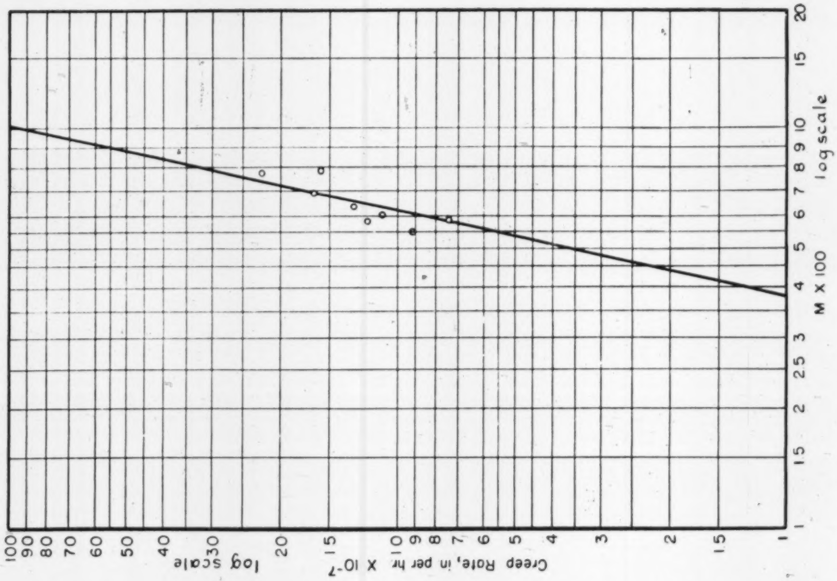

FIG. 17.—Log-Log Creep Stress Relation for Bending.

in Fig. 15. Table V gives the percentage difference between theory and test results.

Based on the creep rate-stress relation given by Eq. 1, a theory predicting the creep rates in pure torsion has been developed (5). By this theory the creep rate can be shown to be:

$$C_t = \frac{\theta}{l} = \left(\frac{180L}{\pi r}\right)\left(3^{\frac{n+1}{2}}\right) B \left(\frac{M_t r}{J}\right)\left(\frac{3n+1}{4n}\right)^n \quad \ldots\ldots (4)$$

where:

B and n = the tension creep experimental constants defined in Eq. 1

M_t = the twisting moment,

θ/l = C_t = creep rate in torsion,

r = radius of the cross-section,

J = $\pi r^4/2$ = polar moment of cross-section, and

L = gage length.

Figure 16 shows that the experimental and theoretical torsion creep rate-moment relations are in good agreement. Table VI gives the percentage difference between the theoretical and experimental values shown in Fig. 16. Figures 17 and 18 correspond to Figs. 15 and 16 except that the creep rate-moment values are plotted on a log-log basis. An examination of Figs. 15 to 18 and Tables V and VI indicates that the agreement between theory and tests is reasonably good, when it is considered that this is a new field of study.

CONCLUSIONS

For the polystyrene tested under the conditions described, it can be concluded that:

1. The minimum creep rate, C, -stress, S, relation for tension may be expressed by the relation $C = BS^n$; 2. The minimum creep rates for both pure bending and pure torsion can be predicted approximately by the theory which uses the tension creep constants. This paper has dealt only with the engineering aspects of creep. A consideration of the molecular structure as related to creep is given in a separate paper (6). Also, correlation of creep properties with other anelastic properties such as dumping capacity is treated separately in the following paper by Sauer and Oliphant (7).

Acknowledgments:

This investigation was conducted by the School of Engineering of The Pennsylvania State College under the sponsorship and with the financial assistance of the Office of Naval Research, Navy Department. Mr. George Cuff, Research Assistant, obtained the test data and plotted the results. Mr. C. C. Hsiao was responsible for the determination of the control test results. Special equipment and specimens were made by Mr. Melvin Aikey. Mr. J. A. Sauer, Head of the Mechanics Department, gave valuable assistance during the course of this investigation and in the preparation of this paper.

TABLE VI.—COMPARISON OF THEORETICAL AND EXPERIMENTAL TORSION CREEP RATES.

Specimen	Torque, M_t, in-lb.	Creep Rate, deg. per in. per hr.		Difference, per cent
		Experimental	Theoretical	
No. 1	326.0	6.12×10^{-3}	4.60×10^{-3}	−25
No. 2	305.5	3.82	3.35	−12
No. 3	280.0	3.35	2.75	−18
No. 4	272.0	1.82	1.82	0
No. 5	269.5	1.50	1.65	+10
No. 6	241.0	1.25	1.15	−8
No. 7	221.0	1.03	0.80	−22
No. 8	178.0	0.60	0.37	−38
No. 9	177.0	0.47	0.30	−36
No. 10	113.1	0.20	0.08	−60

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(2) J. Marin, "Static and Dynamic Creep Properties of Laminated Plastics for Various Types of Stress," National Advisory Committee for Aeronautics, *Technical Note 1105*, Washington, February, 1947.

(3) A. Nadai, "The Influence of Time Upon Creep. The Hyperbolic Sine Creep Law." Timoshenko 60th Anniversary Volume, the Macmillan Co. Inc., New York, N. Y., p. 155 (1938).

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(5) J. Marin, "Mechanical Properties of Materials and Design," McGraw-Hill Book Co. Inc., New York, N. Y. (1942).

(6) J. A. Sauer, J. Marin, and C. C. Hsiao, "Creep and Damping Properties of Polystyrene," *Journal of Applied Physics*, No. 6, Vol. 20 (1949).

(7) J. A. Sauer and W. J. Oliphant, "Damping and Resonant Load-Carrying Capacities of Polystyrene and other High Polymers," see p. 1119 of this volume.

DISCUSSION

MR. G. R. GOHN[1] (*presented in written form*).—The theory developed by the authors to show the relation between minimum creep rates in tension and minimum creep rates in pure bending or in pure torsion are indeed interesting. Without questioning the validity of those relationships, which appear to be reasonably well substantiated by the experimental and theoretical data given in Tables V and VI of their paper, I should like to point out one of the limitations inherent in the basic equation

$$C = BS^n \tag{5}$$

which the authors have used to demonstrate the relation between the minimum creep rate in tension and stress.

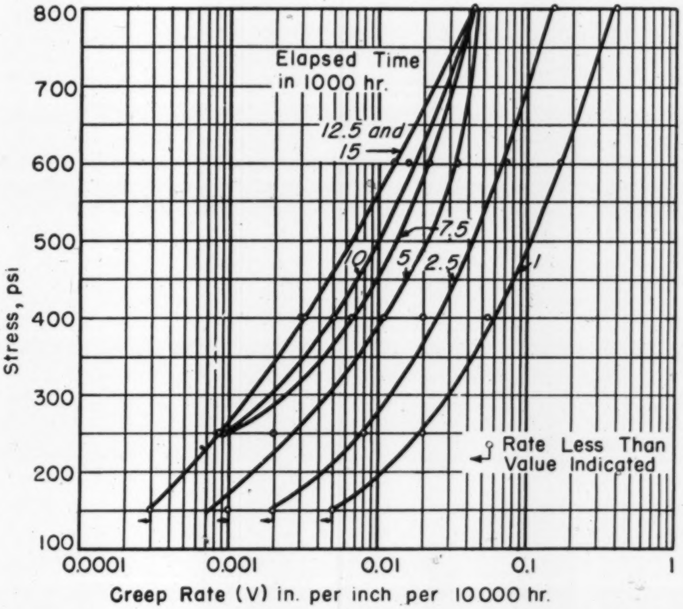

FIG. 19.—Creep Rate *versus* Stress for Compression Molded Polyethylene (PM-2) Sheet Sample A (Clear).

In Eq. 5, C is defined as the minimum creep rate, a value which the authors have derived from creep tests covering a period of only 1000 hr. Our own experience gained from long-time creep tests on metals at stresses within the plastic range and from similar creep tests on polyethylene, a high molecular weight polymer which is discussed by Messrs. Cummings, Ellis, and myself in a paper[2] presented before this meet-

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[1] Member of Technical Staff, Bell Telephone Laboratories, Inc., New York, N. Y.

[2] G. R. Gohn, J. D. Cummings, and W. C. Ellis, "The Creep Characteristics of Compression Molded Polystyrene and Other High Polymers," see, p. 1139 of this publication.

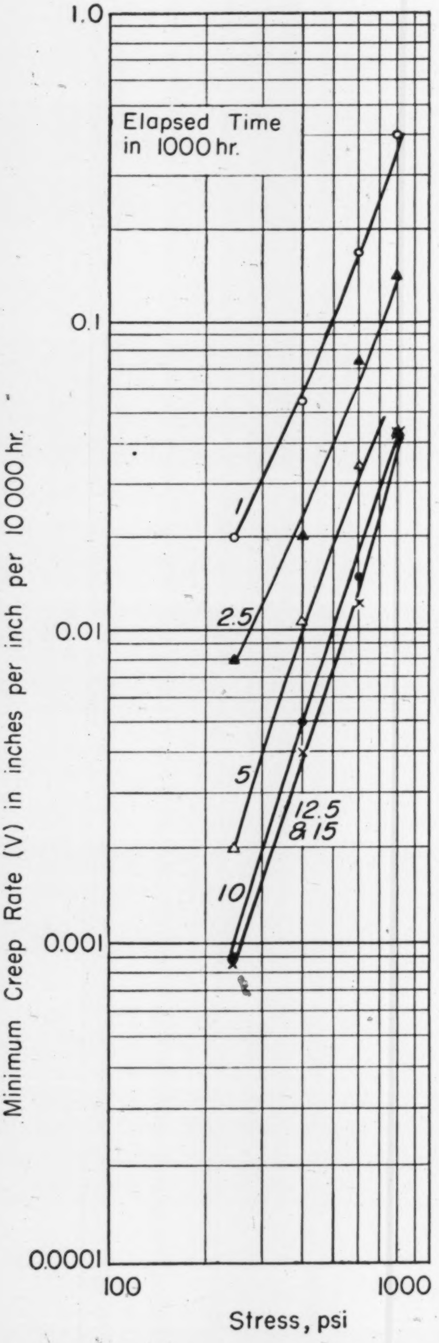

FIG. 20.—Relation Between Minimum Creep Rate, Stress and Time for Compression Molded Polyethylene (PM-2) Sheet Sample A (Clear).

ing of the Society, indicate that minimum creep rates—usually considered to be synonymous with a steady or constant creep rate observed during the second stage of creep—seldom are obtained from tests of such short duration. Reference to Fig. 3 of the latter paper shows that even after 20,000 hr. of continuous loading, the creep rates for specimens of clear compression molded polyethylene sheet (lot A) have not reached a minimum for specimens loaded at stresses ranging from 250 to 800 psi. This is illustrated by the data presented in the accompanying Fig. 19 which shows the relation between stress and minimum creep rates v as calculated from the tangent to the elongation-time curves at various time intervals ranging from 1000 to 15,000 hr. At lower stresses, the increase in strain is less than the precision of the method of measurement and hence the data do not permit the calculation of useful creep rates.

If we accept Eq. 5 as representing the relationship between the minimum creep rate and stress, then

$$\log C = \log B + n \log S \quad \ldots\ldots (6)$$

This equation represents a straight line on a log-log plot for stress *versus* creep rate in which n is the slope of the straight line and B is the ratio of $\frac{C}{S^n}$. If the data shown in Fig. 19 are replotted on a log-log basis, as shown in Fig. 20, it appears that the relationship between log stress and log creep rate is essentially linear for the polyethylene studied. However, the displacement of the various straight lines from left to right with increasing loading times indicates that B is not a constant but a function of time. Similarly, the change in slope of the various lines with increasing time indicates that n is also a function of time and not a constant.

Now we do not believe that either B or n are functions of time except when C is not equal to the minimum creep rate. However, if the values of B and n are not calculated for minimum or steady creep rate data, then the use of Eq. 5 to calculate creep rates at other stress levels will be in error.

I should like to ask the authors whether or not the creep rate data reported in Table II of their paper are minimum creep rates. As previously indicated, our own test data on polyethylene as well as data reported by Findley and Worley in NACA Note No. 1560 on the creep characteristics of five laminated materials, indicate that much longer periods of time are required to obtain minimum creep rate data. In fact, there is some question whether or not the creep curves ever show a steady or minimum creep rate. Under these conditions, do the authors still consider that Eq. 5 can be used to calculate creep rates for any time period other than that used in obtaining the rate data from which B and n were calculated? Also, how does the determination of B and n from creep rates other than minimum values affect the equations developed for pure bending or pure torsion?

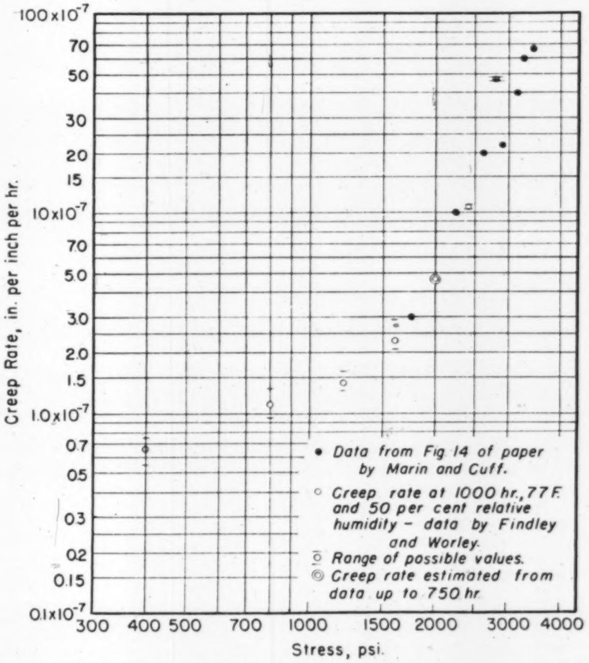

FIG. 21.—Log-Log Plot of Creep Rate *versus* Stress for Polystyrene in Tension.

MR. W. N. FINDLEY.[3]—Since the authors have analyzed their data for tension creep rate of polystyrene on the basis of a power function of stress (authors' Eq. 1), it may be of interest to consider another point of view. An examination of these data as presented in Fig. 14[4] discloses that they may be represented about equally well by an exponential equation as shown by the fact that the data form nearly a straight line on a plot of log creep rate *versus* stress. Since the exponential function is a good approximation of the hyperbolic-sine function for relatively large values of the stress, it may also be possible to represent the authors' data by an hyperbolic-sine function. The equation $v = 0.26 \sinh \frac{\sigma}{540}$ represents the authors' data fairly well (v is the creep rate and σ is the stress). There is a theoretical basis for expecting a hyperbolic-sine relation which is to be found in studies of activation process.[5]

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[3] Research Associate Professor of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

[4] The plotted values for two points seem to differ somewhat from the values in Table II.

In connection with these speculations it may be of interest to consider the creep rate data obtained by the writer[6] for tension creep tests at the same temperature and humidity used by the authors (see Fig. 21). These data were obtained from tests of a polystyrene made by the same manufacturer and having the same molecular weight of about 68,000 (Staudinger).

In Fig. 21 the data obtained by the authors as well as that obtained by the writer are shown plotted on logarithmic coordinates. It is evident that the agreement is reasonably good over the interval of stress values covered by both tests. It is also apparent that the data obtained by the writer at lower stresses indicates that the relationship between creep rate and stress was not a power function for the writer's tests since the data form a curve rather than a straight line.

The data obtained by the writer were represented more accurately by an hyperbolic-sine function than a power function. If the writer's datum at the largest stress is neglected, the remaining creep rates fit the above hyperbolic-sine equation within about $\pm 0.4 \times 10^{-7}$ in. per in. per hr.

The above observations raise a question as to whether the results obtained by calculating the bending creep rate from the tension creep rate would be altered by using an exponential or an hyperbolic-sine function instead of the power function to describe the relation between creep rate and stress.

It would also be of interest to know what happens to the stress distribution in a beam after creep has occurred when the creep rate is an exponential or an hyperbolic-sine function of stress and also when the creep rate is considered to be a power function of stress. For one of the family of power functions (namely the first power) it has been shown that the stress distribution is not altered by creep.[7] This is the case of viscous creep.

The final question concerns the value of Poisson's ratio for polystyrene. The authors have obtained excellent agreement between measurements of this illusive quantity by two different methods. However, the value reported by the authors (about 0.32) differs from the value previously reported (0.48) for polystyrene.[8] It would be of interest to know whether there was a fundamental difference between these two polystyrenes that would account for the difference. In this connection some investigators have considered that the more nearly a material approaches a liquid the closer the value of Poisson's ratio approaches 0.5 (the value corresponding to no change in volume during straining at small strains), and that a polymer which crystallizes on stretching will show a value of Poisson's ratio greater than 0.5.

MR. J. A. SAUER.[9]—The study which the authors are making of the creep-time relations for polystyrene specimens under tension, torsion, and bending loads is useful not only because of the design implications of the data, but also for the additional light that is thrown on the

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[5] W. Kauzmann, "Flow of Solid Metals from the Standpoint of the Chemical-Rate Theory," *Transactions*, Am. Inst. Mining and Metallurgical Engrs., Inst. Metals Div., Vol. 143, p. 57 (1941).

[6] Unpublished data.

[7] A. M. Freudenthal, "The Inelastic Behavior of Engineering Materials and Structures," John Wiley & Sons, Inc., New York, N. Y., in press.

[8] Schmidt and Marles, "Principles of High-Polymer Theory and Practice," p. 260, McGraw-Hill Book Co., Inc., New York, N. Y. (1948).

[9] Department of Engineering Mechanics, School of Engineering, The Pennsylvania State College, State College, Pa.

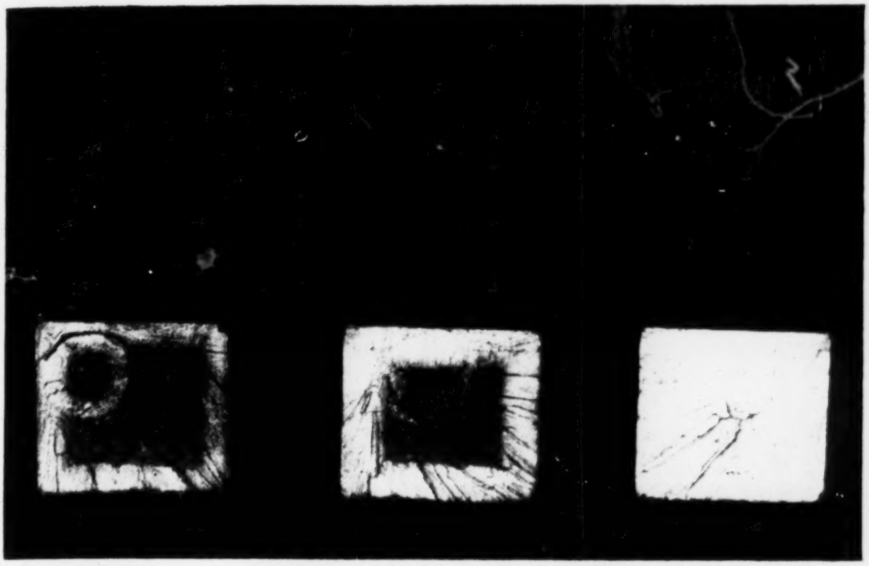

FIG. 22.—Tensile Creep Specimens of Polystyrene Subject to Different Stresses and Different Durations of Load Application.

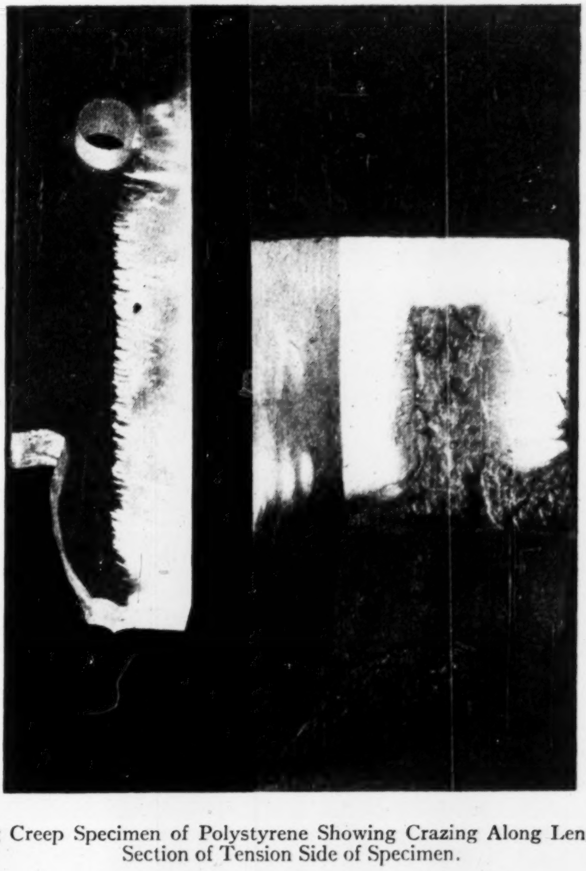

FIG. 23.—Bending Creep Specimen of Polystyrene Showing Crazing Along Length and on Cross-Section of Tension Side of Specimen.

problem of the cause and development of "crazing." "Crazing" is the phenomenon whereby a previously transparent material, under the action of stress or a solvent, or both, begins to lose its transparency. Light is reflected rather than transmitted, presumably by the initiation and spread of mechanical openings or cracks.

A study of the fractured surfaces of the polystyrene creep specimens shows that the amount of crazing increases with increase of stress for a given time of load application and increases with time of load application for a given stress. Figure 22 shows a photograph of the fractured surfaces of several polystyrene tensile creep specimens. The crazing area is the highly reflective region which for one specimen extends across the entire cross-section. Under a microscope, the crazing cracks, not to be confused with the visible radial fracture cracks of the photograph, are seen as tiny openings progressing inward from the surface in a direction at right angles to the direction of the applied tensile stress.

Figure 23, which shows one of the polystyrene bending creep specimens, indicates that crazing occurs only under tensile stress, not under compressive stress. The cross-sectional view of the tensile half of the specimen also pictures the growth of the region of crazing inward from all surfaces.

The development of crazing is undesirable for several reasons. First of all, it may produce severe variations in the value of some of the mechanical properties of the material. Secondly, loss of transparency frequently means that the plastic material can no longer serve its particular function. In order to overcome this condition it is essential that an adequate theory of "crazing" be developed. Experiments such as the present ones described by the authors are helpful in providing the factual information required for development of a suitable theory.

MR. J. MARIN (*author*).—The main questions raised by Messrs. Gohn and Findley are related to the accuracy of the log-log method when used to interpret the creep rate-stress relations. Within the limits of the stresses and times investigated by the authors, the log-log method appeared to be adequate. It should be noted that although the other empirical equations suggested may fit the data better for the times covered by the test, they may not do so when the test data are extrapolated. In fact, a study of methods of interpretation of creep data by the authors showed that an empirical creep-time relation agreed well with the test data when the first 1000 hr. of the test were considered. However, when this relation was extrapolated to several thousand hours, the values were not in as good agreement with the test data as the more approximate log-log method. The log-log method of interpretation has also an advantage in the development of mechanics of creep. That is, relations such as those used for bending and torsion creep based on the log-log tension creep rate-stress equations are easily derived. When other empirical creep-stress relations are used, however, mathematical difficulties are encountered. What is needed is a creep-stress relation which agrees adequately well with the test data and at the same time can be used in the development of the mechanics of creep.

Mr. Sauer's discussion of the "crazing" problem is interesting and his comments are appreciated.

SOME PROBLEMS IN THE SAMPLING OF BULK MATERIALS*

By Louis Tanner[1] and W. Edwards Deming[2]

Synopsis

The sampling of lots of bulk materials for the purpose of estimating the total weight and some quality characteristic presents various kinds of difficulties, both theoretical and practical. The fundamental character of a statistical plan is demonstrable and controllable precision. In order to use the statistical theory for the sampling of finite populations, it is necessary for the shipment to be divisible into sampling units in such a manner that every particle of the shipment lies in one and only one sampling unit, and that all of any unit and no material from any other may be drawn in a routine manner from the lot. This condition is met by packaged materials, an example being wool in bales, from which cores may be drilled in specified positions. A sample of bales may be drawn from the shipment, and a sample of cores may be taken from the sample bales, these cores then to be tested to furnish an estimate of the average quality of the shipment. The total weight of the shipment may be estimated from the weights of the sample bales. Statistical theories have been developed and are here applied in the development of procedures for sampling sugar, tobacco, and wool, and for regulating the precisions of the estimates. Such methods have wide applicability. However, other types of statistical procedures, possibly involving theories for the analysis of an infinite supply, must be developed for materials such as a pile of coal which, for purposes of routine sampling, cannot readily be divided into definite small units. Indications point to distinct advantages of sampling such materials at the source of supply. Hazardous biases and uncontrolled errors of sampling may be encountered through failure to regard statistical principles.

Two Types of Problems

In facing the problems of the sampling of bulk materials one encounters two broad types of physical problems:

A. Materials like piles of coal or ore in which no unique subdivisions may be specified as sampling units that will be practicable for a routine sampling operation.

B. Materials in packages, bales, or bags, or any material that may be subdivided into unique sampling units that are practicable for a routine sampling operation.

A material may change from type A to type B. For example, a type A material, if arrangements are made to draw samples periodically from a conveyor belt during a loading or unloading operation, is during this operation no longer type A but type B.

Statistical theories and a growing

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[2] Adviser in Sampling, Executive Office of the President, Bureau of the Budget, Washington, D. C.

background of experience are being developed by which many materials, particularly those of type B, may be sampled for estimating the weight and quality of a lot. Much new research is being carried on, with the result that costs of sampling and testing are constantly being lowered and some progress is being made in devising new methods for converting certain type A materials to type B.

The particular theory to be applied to the materials of type B is known as the theory for sampling finite populations. This theory has heretofore been developed and applied mostly in the sampling of human populations and farms, and for wholesale and retail business establishments. The miniature monthly census of the population in the United States and a similar quarterly census in Canada are examples: out of these studies come very important figures for business and government, such as the monthly or quarterly report on employment and unemployment, indexes of the prices of food and clothing, and indexes of business activity.

Extension and modification of these procedures to the samplng of physical materials have commenced only recently. The next part of this paper describes an application of statistical theory to some of the problems of sampling shipments of sugar, wool, and tobacco.

The outstanding characteristic of a statistical method of sampling is the controllable and demonstrable precision of its results, which are attained at minimum cost. But before a statistical theory can be applied, certain conditions of sampling must be met. Briefly, sampling depends on the theory of probability. The theory for sampling finite populations demands that every particle of a lot have a definite and known probability of being drawn into the sample: otherwise the calculation of the precision of the results cannot be carried out. This condition is met by materials satisfying the definition given for type B. For such materials it is possible to perform random operations of sampling and to specify by number or code that certain particular sampling units are to be included in the sample, with reasonable assurance that in a routine procedure of sampling, all of the material contained in any of the units so designated for the sample will be included, and all else will be excluded.

Type A materials are those for which no practical and unequivocal sampling units can be specified in routine operations. One might specify, for example, that a pile or car of coal is to be sampled by extracting certain cubes or parallelepipeds, defined as located so many feet from the top and having certain other spacial coordinates. It would be impossible, though, as a regular routine operation, for a worker to draw into the sample the contents of any such sampling unit and to exclude all material not intended for this unit. Under such circumstances a material fails to meet the fundamental criterion of a unique probability for every particle, and it is therefore type A.

The sampling of materials of type A is thus by definition not open to the methods that are used for materials of type B. When samples are drawn from a material of type A, the drawing must too often depend on human judgment. Such dependence, experience demonstrates, is hazardous, as severe biases often develop. As a matter of fact, biases are the rule, not the exception. No statistical measure of precision can be calculated for a judgment selection.

The sampling of materials of type A is not hopeless, however, but calls for ingenuity and a new attack. If a material can be sampled off a conveyor belt at specified intervals, it is, in effect, a material of type B, no matter how it is piled up afterward.

In this paper we intend merely to state some of the problems of bulk sampling and to describe certain particular solutions to some of the problems that are encountered with materials of type B in the Bureau of Customs.

SOME APPLICATIONS OF STATISTICAL THEORY TO BULK MATERIALS OF TYPE B

Theory.—As stated earlier, a statistical plan for sampling a lot of product is expected to provide estimates of quality and weight with known and controllable errors of sampling, and to provide this control at minimum cost. The errors of sampling are controlled by the size of the sample and the procedure of drawing it. One sample design is better than another if it yields the desired precision at a lower cost than the other plan. Mathematical formulas are available which give the sampling errors corresponding to different designs, and for the determination of the most economical design.

In the theory to be applied here it is assumed that the material to be sampled has been divided into distinct units in some suitable manner—bales or packages, hourly production, etc.: in other words, the material is of type B. The problem is to sample a lot composed of a number of such units. In the general case, each of these primary units is composed of a set of secondary units—shovelfuls, cores, sub-packages, cuts, or the smallest portion that will be drawn out for testing. Tertiary or higher order units may also occur. In the special case, the primary unit itself is the test portion, in which case the general sampling theory reduces to the well-known simple theory of sampling.

Statistical theory tells us that the size of sample and the most economical design may be computed from the following equations:

Most economical number of secondary units per primary unit:

$$k = \frac{\sigma_w}{\sigma_b}\sqrt{\frac{c_1}{c_2}} \quad \ldots\ldots\ldots\ldots (1)$$

Number of primary units to be drawn into the sample:

$$n = \frac{N(\sigma_w^2 + k\sigma_b^2)}{Nk\left(\frac{E}{t}\right)^2 + k\sigma^2} \quad \ldots\ldots\ldots (2)$$

For the special case, where there are only primary units:

Where previous measurements have not been made:

$$n = \left(\frac{tV_x}{E}\right)^2 \quad \ldots\ldots\ldots\ldots (3)$$

Where previous measurements have been made:

$$n = \left(\frac{tV_c}{E}\right)^2 \quad \ldots\ldots\ldots\ldots (4)$$

where:

c_1 = cost of preparing a primary unit for sampling,
c_2 = cost of taking a secondary unit from a primary unit,
E = allowable uncertainty of the sample mean,
k = number of secondary units to be drawn from each sampled primary unit,
N = number of primary units in the lot,
n = number of primary units to be sampled,
t = probability factor,
V_x = coefficient of variation of the quality between primary units,
V_c = coefficient of variation of the ratio of the second quality measurement to the first,
σ_b^2 = variance of the quality between primary units, and

σ_w^2 = variance of the quality between secondary units, within a primary unit, averaged over all primary units.

Often the required information may be reliably estimated from existing data. If not, it may be developed by suitable investigation. Continuous evaluation of the pertinent statistics is possible by the adoption of suitable ways of keeping records.

Illustrations of Application.—The sampling theory given above has been successfully applied on a large scale to a variety of bulk commodities. Several cases are here described briefly as illustrations.

The simplest application of sampling theory is the case where the primary unit is the test portion. An example of this occurs in the weighing of imported refined sugar. This commodity arrives in large lots, about 43,000 standard size bags containing approximately 100 lb. each. The weighing is usually done in drafts of 8 bags at the warehouse after damaged bags, about 1.4 per cent of the total, have been segregated for separate handling. A study showed that the coefficient of variation, V_x, of the draft weights of sound bags of refined sugar was stable and averaged about 0.1 per cent. From Eq. 3 it is found that the number of random drafts that must be weighed in order that errors due to chance may be no greater than ±0.1 per cent when $t = 3$ (a risk considered acceptable for this commodity) is 9. On the basis of this information a convenient sample size of 25 drafts was specified to insure obtaining an average bag weight for the entire cargo with a precision of better than ±0.1 per cent.

The potential time and labor savings with a sample weighing method such as this is obviously considerable.

Had segregation of the damaged, partially empty bags not been possible, as is the case with commodities weighed at the time of discharge from the vessel, the coefficient of variation of the draft weights would have been higher, perhaps so high as to require an uneconomically large sample size to achieve the desired precision. In such cases, and in general whenever individual package weights are not standard or differ considerably, a "calibration" technique may be employed. For most commodities there is available the producer's individual package weights on the basis of which commercial transactions have been conducted. Due to changes that usually occur in transit (moisture absorption, damage, etc.), the received or settlement weights may differ considerably from the original weights, necessitating reweighing. In such cases the average ratio of the second weight of a sample to the original weight of the same packages may be used as a conversion factor to be applied to the total original weight of the lot. The coefficient of variation of the conversion factor, V_c, must be known in order to calculate the size of sample required to achieve a prescribed precision.

An example of the use of this "calibration" technique is the weighing of imported cigarette leaf tobacco, of which some 100,000,000 lb. are imported annually. This commodity arrives in lots of several thousand bales of various sizes ranging in weight from 10 to 300 lb., according to source. Previous Customs practice was to weigh each package individually—a very accurate but slow and expensive procedure. Individual bale weights at the time of shipping are available, but they are not considered sufficiently close to the landed weight to serve as the basis for the assessment of duty, nor for some commercial purposes.

It was found that the coefficient of variation of the bale weights averaged about 3.5 per cent and ranged from 1.5

per cent to 9.4 per cent. This statistic is therefore not satisfactory because so large a sample would be required for any reasonable degree of accuracy that material savings in weighing would be impossible. The coefficient of variation of the conversion factor, however, was found to be stable, averaging about 0.7 per cent except for bales of Greek tobacco for which the average was about 2.5 per cent. On the basis of these values, Eq. 4 shows that a sample size of 100 from shipments of most cigarette tobacco (900 for lots of Greek tobacco) is adequate to achieve a precision of ±0.25 per cent, a level considered satisfactory in protecting both the government and the importer against a material loss of revenue or overcharge in duty on any one importation. On the average, these sample sizes represent a saving of from 75 to 95 per cent in the number of weighings.

These two illustrations are obviously simple applications of familiar sampling theory involving only primary units. An instructive case involving both primary and secondary units, and therefore a more general illustration of the application of statistical theory to the sampling of bulk materials, is the sampling of raw wool for the determination of its clean wool content. This case is but one of many similar instances covering a wide variety of products.

Raw wool appears in commerce in lots of various sizes, sometimes as high as 3000 bales or bags, averaging about 100 units. The packages range in weight from 200 lb. to 1200 lb. but are fairly uniform in this respect for any one source. The wool contains a number of impurities, the percentage of which may vary widely, as much as 30 per cent, both between bales in a lot and between portions within a bale. The evaluation of a lot of this commodity for any given grade and quality depends on the quantity of wool contained therein. Customarily this factor is estimated visually by qualified appraisers, but the need for a reliable objective method for determining the clean wool content without processing all or a large fraction of the lot has long been felt. The major obstacle to the realization of such a method has until recently been the unreliability of the only type of small sample that could be taken, usually a few handfuls or fleeces selected as representative on the basis of the sampler's judgment. This particular difficulty has been eliminated by the development of a practicable sampling tool that can penetrate into a bale of wool and remove therefrom a relatively small core. The question arises as to how many such cores should be taken, and from how many bales.

In the sampling of this commodity the primary unit is the package, the secondary unit the core. When reliable estimates of the within-bale and between-bale variances are available, different sampling plans may be followed, each of which yields a sample of the same precision. Thus, k_1 cores may be taken from each of n_1 randomly selected bales in the lot, or k_2 cores may be taken from each of n_2 bales. For any chosen value of k, the corresponding value of n is given by Eq. 2.

Systematic studies were made of the magnitudes and stability of σ_w and σ_b for many commercial lots of most types and grades of wool from different sources throughout the world. As was to be expected, no one single pair of values covered all the wools investigated. However, it was found that, when grouped in a relatively small number of broad classifications according to origin, end use, and type of package, these statistics were fairly stable and could serve as sufficiently reliable estimates for sampling purposes. Some typical vaues are shown in Table I.

By using these estimates of σ_w and σ_b in Eq. 2, schedules may be prepared giving, for each class of wool, the number of packages to be sampled for various lot sizes and for various numbers of cores per package, at any required level of precision. Table II illustrates such a schedule.

Each of the four plans illustrated in Table II will result in a sample of the same precision, but not at the same cost. There are two operations in obtaining a core of wool: first, positioning the bale, and second, boring it. Each operation has its own cost,[3] c_1 and c_2 respectively, and their ratio may vary widely depending on the existing conditions. For example, if sampling takes place at the time the individual bales are being weighed or moved to storage, there is virtually no additional cost for positioning the bale, and $\frac{c_1}{c_2}$ might be, for example, 1.0. On the other hand, if the bales are already stored in piles in a warehouse and the piles have to be broken down to permit sampling, the cost ratio might easily exceed 25. The most economical plan of samplng is the one which uses that number of cores per bale given by Eq. 1.

TABLE I.—CLASSIFICATION OF PACKAGED GREASY APPAREL WOOLS FOR SAMPLING PURPOSES.

	σ_w	σ_b
Argentina	2.5	2.5
Australia	1.5	4.0
Chile	2.0	5.0
Uruguay	2.0	1.5
Domestic	4.5	2.0

σ_w = the estimated standard deviation of the per cent clean wool content of individual cores within packages in a lot.

σ_b = the estimated standard deviation of the per cent clean wool content between packages in a usual commercial lot.

The usefulness of this method has been proved in actual practice. One testing organization is regularly called upon to sample lots of domestic wool stored in warehouses. For this wool $\frac{\sigma_w}{\sigma_b}$ is about 2.25, and under the conditions of sampling, $\frac{c_1}{c_2}$ is approximately 20. Accordingly, the sampling plan followed is to take 10 cores from each package, the number of packages being determined from Eq. 2. A second organization is able to sample its imported carpet wool as it is being trucked into the mill. In this case $\frac{c_1}{c_2}$ is about 1 and $\frac{\sigma_w}{\sigma_b}$ also averages about 1, so that the sampling plan used is one core per sampled bale. The two plans differ considerably for the same precision, yet each is the most economical plan possible under the different conditions faced by the two organizations.

TABLE II.—SAMPLING SCHEDULE SHOWING NUMBER OF PACKAGES TO BE SAMPLED FROM A LOT FOR WHICH $\sigma_w = \sigma_b = 2.5$, FOR A PRECISION OF 1.0 AT A PROBABILITY OF 0.95.

Number of Packages in the Lot	Number of Cores per Sampled Package			
	1	2	4	6
25	25	19	16	15
50	34	25	21	20
75	38	29	24	22
100	40	30	25	24
150	43	33	27	25
200	45	34	28	26
300	47	35	29	27
500	48	36	30	28
1000	49	37	31	29

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[3] The cost of testing should also be included in deciding on the most economical plan. If each secondary unit is tested individually, c_2 should include the unit test cost. In the case of wool, the cores are composited and a single test is performed on the composite sample.

DISCUSSION

MR. B. A. LANDRY.[1]—I should like to ask the author, when he spoke of sampling bales of wool, whether the bales on which the borings were made were selected in a systematic, orderly fashion or whether some other means of selection was used.

MR. LOUIS TANNER (*author*).—The number of bales to be bored is designated in accordance with a schedule based on the principles stated in the paper. The selection of the particular bales in the lot is either random or planned, depending on circumstances. If the lot has not been segregated into groups of bales according to some quality characteristic, such as type or grade, which may have a bearing on clean wool content, the selection is usually a random one. In such case, however, the sampler is instructed to cover the entire lot, if possible, not merely those bales that happen to be most accessible. For example, he might be told to bore the first two bales he comes to, skip one, bore the next two, skip one, and so on.

If the lot has been segregated into groups, an approximately proportionate number of bales from each group is sampled, the selection of the bales from each group being made in the manner just described.

MR. LANDRY.—I am interested in hearing what some people call "randomness." I did not get further elucidation in this case; as far as I can see, the authors sampled it in an orderly or systematic way, rather than randomly, and I commend them for it, because I think that if you introduce randomness in its true sense in a sampling problem like this you would get away from greatest economy.

I should like to ask another question. Have the effect of changing the diameter or length, or volume of the core been investigated?

MR. TANNER.—Yes. We have made an intensive study of the effect of different tube diameters and depths of penetration on the within-bale component of variance and on the cost of sampling and testing importations of wool. It was found that we could get the same accuracy more economically by greatly reducing the diameter of the tube and slightly increasing the depth of penetration.

This result is purely because of the character of the merchandise. We found that the clean wool content of contiguous small areas in any layer was rather constant, whereas this quality varied considerably between layers. Along a diameter of the tube, the variation was small; along the axis, it was relatively large. By reducing the diameter to one-fourth its former value and increasing the penetration by 20 per cent, cores weighing only about one-tenth as much could be taken, and yet the variance between cores of each type was the same, or even slightly in favor of the smaller core. Handling and testing a smaller weight of sample is more economical.

This favorable result might not be true for other types of material. It happens to work out satisfactorily for most baled wools because fleeces are usually laid out in a package like the pages of a book, and the contiguous small areas of different fleeces vary more than do contiguous portions of the same fleece.

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[1] Supervisor, Fuels Research, Battelle Memorial Institute, Columbus, Ohio.

MR. LANDRY.—If I understand correctly, if the length of the cylinder had been held constant and its diameter increased, there would have been no advantage resulting from the fact that a sample of larger size had been taken because the variation was in the length.

In other words, if the length had been held constant and the diameter increased, there would have been no advantage.

MR. TANNER.—There might be a very slight advantage, statistically. However, an increase in diameter is sometimes advantageous practically. Some wools are so loosely packed that to successfully cut a core and retain it within the tube, a large diameter is required. A small diameter tube would merely push such wool aside without cutting it.

The advantage, then, is purely mechanical for certain wools. In most cases, there would not be greater accuracy corresponding to the increase in weight due solely to a larger diameter tube.

SUMMARY OF PROCEEDINGS OF THE CHICAGO SPRING MEETING—SYMPOSIUM ON AGING OF RUBBERS

The 1949 Spring Meeting of the Society was held in Chicago, Ill., at the Edgewater Beach Hotel on March 2, 1949, in conjunction with A.S.T.M. Committee Week.

The Symposium on Aging of Rubbers was sponsored by Committee D-11 on Rubber and Rubber-Like Materials through a Special Symposium Committee consisting of the following: G. C. Maassen, *Chairman*, R. T. Vanderbilt & Co., Inc.; T. A. Bulifant, Barrett Division, Allied Chemical and Dye Corp.; H. E. Charles, Hazard Insulated Wire Works Div., The Okonite Co.; L. E. Cheyney, Waterproof-Ohio Div., Pollock Paper Corp.; L. V. Cooper, Firestone Tire and Rubber Co.; A. E. Juve, The B. F. Goodrich Co.; H. E. Outcault, St. Joseph Lead Co.; M. G. Schoch, Jr., Hewitt-Robins, Inc.; and R. D. Stiehler, National Bureau of Standards.

The symposium was formally opened by President R. L. Templin. Mr. Simon Collier, Johns-Manville Corp., acted as General Chairman at the Symposium Session and Mr. G. C. Maassen acted as Technical Chairman.

The following six papers that were presented are listed below:

The Mode of Attack of Oxygen on Rubber—A. M. Neal and J. R. Vincent
Oxygen—Absorption Methods—Their Utility and Limitations in the Study of Aging—J. Reid Shelton
Chemical Changes in Elastomers and Antioxidants During Aging—John O. Cole
Physical Aspects of the Aging of Rubbers—M. C. Throdahl
The Effects of Light and Ozone on Rubber—John T. Blake
The Effect of Temperature on the Air Aging of Rubber Vulcanizates—M. G. Schoch, Jr., and A. E. Juve

The papers together with discussions are issued as A.S.T.M. Special Technical Publication No. 89, entitled, "Symposium on Aging of Rubbers."

SUMMARY OF PROCEEDINGS
OF THE
FIRST PACIFIC AREA NATIONAL MEETING

San Francisco, Calif., October 10–14, 1949

The First Pacific Area National Meeting of the Society was held at the Fairmont Hotel in San Francisco on October 10–14, 1949 with the coöperation of the Northern and Southern California A.S.T.M. District Councils. The General Committee on Arrangements consisted of the following members:

Dozier Finley, *Chairman*, The Paraffine Cos.
C. E. Emmons, The Texas Company
C. F. Ramey, Standard Oil Co. of Calif.
R. F. Blanks, U. S. Bureau of Reclamation
T. P. Dresser, Jr., Abbot A. Hanks, Inc.
W. C. Hanna, California Portland Cement Co.
T. K. May, West Coast Lumbermen's Assn.
W. W. Moore, Dames & Moore

The registered attendance of the meeting was as follows: members, 298; visitors, 396; making a total of 694 plus 113 ladies, or a grand total of 807.

There were 15 technical sessions held at which papers from authors throughout the country were presented. Professor R. E. Davis, University of California was honorary chairman of the technical sessions. The 15 sessions consisted of the following:

SOILS

Monday, October 10, 2 P.M.

Honorary Chairman: R. E. Davis, University of California, Berkeley, Calif.
Chairman: F. J. Converse, California Institute of Tech., Pasadena, Calif.

Electrical Resistivity Method Applied to the Investigation of Construction Materials Deposits—E. A. Abdun-Nur and D. Wantland.

Effect of Rock Content and Placement Density on Consolidation and Related Pore Pressure in Embankment Construction—H. J. Gibbs.

Studies of Construction Problems and Methods of Compacting Different Type Soils to Optimum Density—A. W. Root, W. S. Maxwell and T. E. Stanton.

PLASTICITY AND CREEP OF METALS

Monday, October 10, 2 P.M.

Honorary Chairman: J. G. Morrow, The Steel Company of Canada, Ltd., Hamilton, Ont., Canada
Chairman: J. E. Dorn, University of California, Berkeley, Calif.

Experimental Exploration of Plastic Flow in Sheet Metals—L. R. Jackson and W. T. Lankford.

Forming Parameters and Criteria for Design and Production—William Schroeder.

The Use of Creep Data in Design—Howard C. Cross and L. R. Jackson.

Super Creep-Resistant Alloys—J. W. Freeman, D. N. Frey, E. E. Reynolds, and A. E. White.

FATIGUE OF METALS

MONDAY, OCTOBER 10, 8 P.M.

CHAIRMAN: **R. L. TEMPLIN**, Aluminum Company of America, New Kensington, Pa.

Discussions of a Century Ago Concerning the Nature of Fatigue and Review of Some of the Subsequent Researches Concerning the Mechanism of Fatigue—R. E. Peterson.

Fatigue Strength of Steel Through the Range from ½ to 30,000 Cycles of Stress—M. H. Weisman and M. H. Kaplan.

Fatigue Notch Sensitivities of Some Aircraft Material—H. J. Grover.

Fatigue Characteristics of Aircraft Materials and Fastenings—Thomas Piper, K. F. Finlay and A. P. Binsacca.

BITUMINOUS PAVING MIXTURES

MONDAY, OCTOBER 10, 8 P.M.

CHAIRMAN: **HARMER E. DAVIS**, University of California, Berkeley, Calif.

Corps of Engineers' Method for Design and Control of Asphalt Paving Mixutres—Gayle McFadden and W. C. Ricketts.

History and Theory of Triaxial Testing and the Preparation of Realistic Test Specimens—A Report of the Triaxial Institute—V. A. Endersby.

Application of the Triaxial Test to Bituminous Mixtures—California Research Corporation Method—V. R. Smith.

Application of the Triaxial Test to Bituminous Mixtures—Hveem Stabilometer Method—F. N. Hveem.

DYNAMIC STRESS DETERMINATIONS

TUESDAY, OCTOBER 11, 9 A.M.

CHAIRMAN: **H. D. EBERHART**, University of California, Berkeley, Calif.

Survey of Pick-ups for Dynamic Physical Measurements—Gifford White.

Selection of Recording Equipment for Dynamic Testing—K. D. Swartzel.

Analysis and Interpretation of Dynamic Records—H. C. Roberts.

Examples of Dynamic Testing in the Field of Structures and Materials—Douglas McHenry and H. E. Hosticka.

CERAMIC AND CONCRETE PRODUCTS

TUESDAY, OCTOBER 11, 9 A.M.

CHAIRMAN: **J. W. WHITTEMORE**, Virginia Polytechnic Institute, Blacksburg, Va.

Design and Construction of Reinforced Grouted Brick Masonry and Some Properties Relating Thereto—N. W. Kelch.

Use of Precast Concrete Units in Southern California—C. D. Wailes, Jr.

Some Recent Developments in Vitrified Clay Pipe and Conduit—H. W. Jewell.

Reinforced Concrete Pipe—E. L. Johnson.

APPLICATION OF STATISTICS

TUESDAY, OCTOBER 11, 2 P.M.

CHAIRMAN: **ARTHUR W. CARPENTER**, B. F. Goodrich Co., Akron, Ohio

Economic Relationship Between Design and Acceptance Specifications—E. L. Grant.

Precision and Accuracy of Test Methods—Grant Wernimont.

Use of Statistics to Determine Precision of Test Methods—W. J. Youden and J. M. Cameron.

Johns-Manville Program and Movie on Modern Quality Control—Simon Collier.

CEMENT AND CONCRETE

WEDNESDAY, OCTOBER 12, 9 A.M. AND 2 P.M.

CHAIRMAN: T. E. STANTON, California Division of Highways, Sacremento, Calif.
Why Type II Cement?—F. H. Jackson.
Long-Time Study of Cement Performance in Concrete, with Special Reference to Heats of Hydration—G. J. Verbeck and C. W. Foster.

SYMPOSIUM ON USE OF POZZOLANIC MATERIALS IN MORTARS AND CONCRETES

CHAIRMAN: R. F. BLANKS, U. S. Bureau of Reclamation, Denver, Colo.
Pozzolanic Materials and Their Use in Concretes—R. E. Davis.
Pozzolans Used in Mass Concrete—H. S. Meissner.
Experience with Kansas Aggregates and Pozzolanic Additions—C. H. Scholer.
Effect of Calcination on Natural Pozzolans—R. C. Mielenz, O. J. Glantz, and L. P. Witte.
Effect of the Use of Diatomite Treated with Air-Entraining Agents upon the Properties of Concrete—R. E. Davis and Alexander Klein.
Summary of Methods for Determining Pozzolanic Activity—W. T. Moran and J. L. Gilliland.
Strength, Volume Change and Sulfate Resistance of Mortars Containing Portland-Pozzolan Cements—R. E. Davis, W. C. Hanna, and E. H. Brown.
Studies of Some Methods of Avoiding Expansion and Pattern Cracking Associated with the Alkali-Aggregate Reaction—W. C. Lerch.
Studies of Use of Pozzolans for Counteracting Excessive Concrete Expansion Resulting from Reaction Between Aggregates and Alkalies in Cement—T. E. Stanton.

PETROLEUM: SYMPOSIUM ON HIGH ADDITIVE-CONTENT OILS

WEDNESDAY, OCTOBER 12, 9 A.M.

CHAIRMAN: A. H. BATCHELDER, California Research Corp., Richmond, Calif.
Does Service Performance Justify Higher Quality Lubricating Oils?—W. B. Bassett.
High Detergency Motor Oils—A. B. Boehm and C. O. Tongberg.
Five Years' Experience with Special Heavy Duty Oils—R. E. Jeffrey, Jr. and J. A. Edgar.
Possible Future Military Engine Oils for Ground Equipment—N. L. Klein.

PETROLEUM: SYMPOSIUM ON TURBINE OILS

WEDNESDAY, OCTOBER 12, 2 P.M.

CHAIRMAN: T. A. BOYD, General Motors Corp., Detroit, Mich.
Lubrication Problems and Requirements of Gas Turbine Equipment—F. C. Linn.
Operating Experience and Problems Relative to Lubricating Systems of Steam Turbine Sets for Utilities—V. Estcourt.
Specific Problems Pertaining to Lubrication of Industrial Turbines—A. S. Morrow.
Lubrication of Marine Turbine Propulsion Equipment—F. S. Jones.

PAINT

THURSDAY, OCTOBER 13, 9 A.M. AND 2 P.M.

AIRCRAFT FINISHES

CHAIRMAN: L. A. O'LEARY, W. P. Fuller and Co., South San Francisco, Calif.
Fire-Resistant Finishes for Aircraft—J. A. Jones and R. V. Niswander.
Laboratory Testing of Rain-Erosion Resistance of Aircraft Finishes—J. K. Grace and G. C. Frey.
Methods of Evaluation of Aircraft Primers—E. T. Nelson.

NEW METHODS FOR TESTING PAINTS AND PAINT MATERIALS

CHAIRMAN: C. H. ROSE, National Lead Co., Brooklyn, N. Y.

Resin and Drying Oil Tests—C. C. Hartman, C. F. Pickett, and Francis Scofield.

Evaporation Rate of Hydrocarbons and Their Mixtures—L. S. Galstaun.

Solvent and Thinner Tests—M. B. Chittick.

Tests for Physical and Optical Properties of Paint and Paint Materials—M. R. Euverard and R. S. Hunter.

Electrometric Testing of Paint Films—William Shaw.

Varnish Tests—J. C. Weaver.

Pigment Tests—C. L. Crockett and C. Y. Hopkins.

Laboratory Tests of Protective Coatings Versus Service Results—W. T. Moran and G. E. Burnett.

Accelerated Tests for Corrosion Resistance of Paints on Steel—H. A. Nelson.

Exterior Exposure Tests for Wood and Metal Paints—Wayne Fuller and A. J. Eickhoff.

Traffic Paint Tests—W. C. Vannoy.

Some Aspects of Cold-Check Testing Practice—A Survey of the Furniture Finishes Field—F. H. Lang, I. C. Clare, and W. C. Brown.

WOOD

THURSDAY, OCTOBER 13, 9 A.M.

CHAIRMAN: L. J. MARKWARDT, U. S. Forest Products Laboratory, Madison, Wis.

Studies of the Strength of Glued Laminated Wood Construction—A. L. Freas.

Predicting Durability of Exterior Plywood—N. S. Perkins.

Physical and Mechanical Properties of Second-Growth Douglas Fir—J. B. Alexander.

Strength and Related Properties of Old-Growth Douglas-Fir Infected with Fomes Pini—J. R. Stillinger.

Mechanical Properties of Second-Growth Redwood and Comparison with Virgin Timber—Emanuel Fritz.

CAST IRON

THURSDAY, OCTOBER 13, 2 P.M.

CHAIRMAN: H. BORNSTEIN, Deere and Co., Moline, Ill.

Mechanical Testing and Properties of Gray Cast Iron—C. K. Donoho.

Development, Significance, and Uses of Specifications for Cast Iron—H. Bornstein.

Automotive Cast Irons, Including Brake Drums—R. G. McElwee.

Applications and Uses of Gray Iron Castings, Including Significance of Various Properties of Gray Iron—C. O. Burgess.

Most of the papers listed above will be published either in a later issue of *Proceedings*, in *Special Technical Publications*, or in the ASTM. BULLETIN.

In addition to the above 15 technical sessions, the following symposiums and discussions were presented as part of technical committee meetings held in conjunction with the technical sessions:

Symposium on Modern Chemical and Instrumental Methods for the Determination of Metals in Petroleum Products.

Papers on Wood and Wood Products.

Symposium on the Effect of Fuel Upon Diesel Engine Deposits.

Papers on Concrete and Concrete Aggregates.

Papers on Structural Sandwich Construction and Materials.

Along with the technical sessions listed above, 70 technical committees and subcommittees took the opportunity to hold meetings on the West Coast and acquaint our western members with the procedures involved in developing A.S.T.M. Standards.

The meeting was also highlighed by many entertainment features consisting of a Kick-Off Luncheon on Monday, a President's Reception and Buffet Supper on Tuesday, boat ride on San Francisco Bay on Thursday, and a visit to the University of California on Friday, together with luncheons held each day for members in certain fields covered by the Society: Soils Luncheon Tuesday, Cement Luncheon and Petroleum Luncheon Wednesday, Paint and Wood Luncheons Thursday. In addition several entertainment features were arranged for the ladies including luncheons, scenic tours and a fashion show.

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Improved Single-Unit Schiefer Abrasion Testing Machine—Herbert F. Schiefer, Lawrence E. Crean, and John F. Krasny. Published in ASTM BULLETIN, No. 159, July, 1949, p. 73 (TP133).

Accelerated Testing.

Some Observations on the Accelerated A.S.T.M. Life Test for Electrical Heating Wires—Anton deS. Brasunas and Herbert H. Uhlig. Published in ASTM BULLETIN, No. 161, October, 1949, p. 31 (TP175).

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Acoustical Materials.

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Discussion of the Paper on the Pressure Method for Air Content of Mortars. Published in ASTM BULLETIN, No. 158, May, 1949, p. 65 (TP91).

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The Design of Concrete Mixes Containing Entrained Air—Thomas H. Thornburn, 921. Discussion, 937.

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The Preparation of Concrete for Airport Runways—Inge Lyse. Published in ASTM BULLETIN, No. 161, October, 1949, p. 48 (TP192).

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  A Laboratory-Cast Pin Sample for the Spectrographic Analysis of Copper-Base Alloys—E. W. Palmer, J. P. Irwin, and C. C. Fogg. Published in ASTM BULLETIN, No. 160, September, 1949, p. 41 (TP139).
  Light Metals and Alloys, Cast and Wrought. Report of Committee B-7, 205.
  Magnesium Alloys and Applications—John C. McDonald. Published in ASTM BULLETIN, No. 159, July, 1949, p. 67 (TP127).
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  "Aluminum"—R. L. Templin. Published in ASTM BULLETIN, No. 158, May, 1949, p. 45 (TP71).
  Aluminum Condenser and Heat Exchanger Tubes—J. S. Hamilton and J. J. Bowman. Published in ASTM BULLETIN, No. 159, July, 1949, p. 44 (TP104).
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1949 PAPERS

LIST OF SPECIAL TECHNICAL PUBLICATIONS

In the Proceedings, Volume 48, page 1352, 1948, the Society published for the first time the list of Special Technical Publications that have been published by the Society since its organization. The following are the publications that have been printed during the year 1949 and issued as a separate publication not included in either Proceedings or ASTM BULLETIN.

SPECIAL TECHNICAL PUBLICATION NUMBER	TITLE
88	Symposium on Industrial Gear Lubricants (1949).
89	Symposium on Aging of Rubbers (1949).
90	Metal Cleaning Bibliography (1949).
91	Fatigue Manual (1949).
92	Symposium on Lubrication of High-Speed Turbine Gear Equipment (1949).
93	Symposium on Evaluation Tests for Stainless Steels (1949).

SPECIAL TECHNICAL PUBLICATION NUMBER	TITLE
94	Symposium on Accelerated Durability Testing of Bituminous Materials (1949).
95	Symposium on Insulating Oils (1949).
96	Papers on Radiography (1949).
97	Symposium on Testing Cast Iron with SR-4 Type of Gage (1949).
98	Symposium on Rapid Methods for Identification of Metals (1949).